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In Situ Ozone Data for Evaluation of the  
Laser Absorption Spectrometer Remote  
Sensor: 1979 Southeastern Virginia  
Urban Plume Study Summer Field Program

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EVALUATION OF THE LASER ABSORPTION  
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## SUMMARY

Ozone data from the 1979 Southeastern Virginia Urban Plume Study (SEV-UPS) field program are presented. SEV-UPS, a part of NASA's Tropospheric Remote Sensor Evaluation program, was conducted during the month of August for evaluation of an ozone remote sensor, the Jet Propulsion Laboratory's Laser Absorption Spectrometer (LAS). During the measurement program, remote-sensor evaluation was in two areas; (1) determination of the remote sensor's accuracy, repeatability, and operational characteristics, and (2) demonstration of the application of remotely sensed ozone data in air quality experiments. For the first type of evaluation, two experiments, a Correlative Spiral and a Correlative Box Face, were conducted to provide comprehensive in situ ozone data for comparison with the remote sensor. Each experiment was repeated several times during the August field program. This report summarizes the in situ  $O_3$  data measured during these two experiments and identifies that data to be compared with the remote sensor. The in situ ozone measurements are those measured from an aircraft whose flight plan was specifically designed to provide the correlative data. The Laser Absorption Spectrometer system, flown on a second aircraft, measured ozone burden from the aircraft to the surface. LAS remote sensor data are not presented in this report. The ozone data presented provide six comprehensive in situ data sets from which the remote sensor is to be evaluated. Surface ozone measurements, and surface and aircraft meteorological data are also presented to supplement the aircraft in situ ozone data.

The paper also discusses, in some detail, the instruments flown onboard the aircraft providing the correlative in situ data, as well as the accuracy and validity of the measurements.

## INTRODUCTION

As part of NASA's Tropospheric Remote Sensor Evaluation program, the 1979 Southeastern Virginia Urban Plume Study (SEV-UPS) program was conducted in August to evaluate an ozone remote sensor for the measurement of tropospheric ozone. The ozone remote sensor under evaluation was the Jet Propulsion Laboratory's Laser Absorption Spectrometer (LAS). The field program was a multi-element measurement program consisting of airborne and surface measurements of ozone as well as measurements of ozone precursors, nitrogen oxides and hydrocarbons. In addition, comprehensive meteorological data were obtained to assist in the analysis of the air quality data. Experiments were conducted to provide data for remote sensor evaluation in areas of: (1) determination of the remote sensor's accuracy, repeatability, and operational characteristics for making an ozone measurement, and (2) demonstration of the applicability of remotely sensed ozone data in air quality experiments. Correlative evaluations were performed during 1- to 2-hour experiments in which comprehensive ozone data were obtained using in situ techniques for direct comparison with the remote sensor data. Applicability demonstration experiments consisted of 8- to 12-hour air quality studies of ozone behavior in and around an urban complex. On selected days, the air quality studies such as an aging urban plume experiment were conducted with the expectation that the uniqueness and advantage of remotely sensed ozone data can be demonstrated in the analysis of a typical ozone air quality problem.

The purpose of this report is to summarize the data from those experiments conducted for evaluation purpose 1, listed above. Only the data necessary to document the ozone concentrations in the test area are presented. The report summarizes or defines the ozone data to be compared with the LAS remotely sensed data for each evaluation experiment. In addition, the accuracy and validity of the reported in situ data are discussed. The majority of the data presented was measured onboard the NASA Langley in situ aircraft (Cessna 402), which for these evaluations was a dedicated instrument platform for purposes of in situ correlative ozone data. When appropriate, other data (surface and airborne) are presented to supplement the Cessna results.

#### SYMBOLS AND ABBREVIATIONS

|                       |   |   |
|-----------------------|---|---|
| $\beta_{\text{scat}}$ | - | aerosol scattering coefficient, $\text{m}^{-1}$ |
| chem                  | - | chemiluminescent ozone instrument               |
| dp                    | - | dewpoint temperature, $^{\circ}\text{C}$        |
| e.d.t.                | - | eastern daylight time                           |
| LAS                   | - | laser absorption spectrometer                   |
| NASA                  | - | National Aeronautics and Space Administration   |
| $\text{O}_3$          | - | ozone   |
| ppb                   | - | parts-per-billion, by volume                    |
| ppm                   | - | parts-per-million, by volume                    |
| RTI                   | - | Research Triangle Institute, NASA Contractor    |
| SEV UPS               | - | Southeastern Virginia Urban Plume Study         |
| T                     | - | temperature, $^{\circ}\text{C}$                 |
| UV                    | - | ultra violet or UV absorption ozone instrument  |
| VOR                   | - | very high frequency omnidirectional range       |

#### AIRCRAFT AND SENSORS

For the correlative experiments, two basic instrument aircraft were used: the remote sensor aircraft and the NASA in situ aircraft. Both of these platforms and associated measurement systems will be discussed in this section. For those cases where data are discussed from other measurement platforms or systems, appropriate references will be cited for that system or a brief discussion of the system presented at that point in the text.

## Remote Sensor Aircraft

The remote sensor aircraft was a light, twin-engine, fixed-wing Beechcraft Queen Air operated by the Jet Propulsion Laboratory that was modified to receive the LAS remote sensor. The Queen Air is unpressurized and equipped with routine aircraft navigational avionics and has a flight time of 2 hours at about 250 km/hr. In addition to the nadir-viewing LAS, an in situ UV absorption (ref. 1) ozone sensor was onboard with sample air for the in situ sensor supplied from beneath the fuselage using teflon tubing. The LAS (ref. 2) is designed to remotely measure trace atmospheric gases from aircraft. It contains two carbon dioxide lasers, tunable over a 9  $\mu\text{m}$  to 11  $\mu\text{m}$  wavelength region. The instrument also contains two infrared heterodyne receivers, appropriate optics to aim the lasers at the ground and detect backscattered energy, and signal processing and recording electronics. For  $\text{O}_3$  (operating at 9.5  $\mu\text{m}$ ), the instrument measures total  $\text{O}_3$  burden from the aircraft to the ground. Prior knowledge of the absorption coefficients for  $\text{O}_3$  as well as other atmospheric gases at the operating wavelength, as functions of both pressure and temperature, is required for conversion from differential absorption coefficient to  $\text{O}_3$  burden. Detection capabilities are on the order of 20 ppb-km. The LAS data taken in conjunction with the 1979 SEV-UPS correlative experiments are summarized in reference 3.

## In Situ Sensor Aircraft

The in situ sensor aircraft was a light, twin-engine, fixed-winged Cessna 402 aircraft chartered by NASA Langley and outfitted for in situ air quality measurements. References 4 and 5 describe the aircraft, its sampling system, associated laboratory instrument test programs, and instrumentation. Table I lists the onboard measurement systems used during the 1979 SEV-UPS program. The aircraft is equipped to monitor  $\text{O}_3$ ,  $\text{NO}$ ,  $\text{NO}_x$ ,  $\text{Bscat}$ , temperature, dewpoint, and flight parameters. References 4 and 5 describe the installation of all instruments except the UV absorption  $\text{O}_3$  instrument. This instrument was installed adjacent to the chemiluminescent  $\text{O}_3$  instrument which is described in reference 5. Figure 1 is a sketch of the instrument locations on the aircraft. Flight characteristics of the aircraft during data taking are about 250 km/hr forward air speed, ascent and descent rates of less than 150 m/min., and 4 hours flight time.

All data onboard the aircraft are recorded continuously on magnetic tape. The magnetic tape is digitized and processed in the Langley computer system. Further processing is done with a mini-computer, and data are reported as 10-second averages.

## DESCRIPTION OF CORRELATIVE DATA EXPERIMENTS

As part of the 1979 SEV-UPS summer field program, two different correlative experiments were designed to provide in situ  $\text{O}_3$  data for evaluation of the accuracy, repeatability, and operational characteristics of the LAS remote sensor. The philosophy of each experiment was to define a finite test volume and with in situ measurements document  $\text{O}_3$  concentrations within this test volume while the remote sensor was taking  $\text{O}_3$  burden measurements. The two experiments, hereafter referred to as the "Correlative Spiral" and the "Correlative Box Face," differ mainly in the in situ flight plans used to document existing  $\text{O}_3$  concentrations. Each experiment was flown several times,

investigating different  $O_3$  levels, different remote sensor surface viewing features, and different meteorological conditions. Differences between the designed flight plans and those actually flown were minor and are discussed as the data are presented.

#### Correlative Spiral

Figure 2 shows a representative flight plan for the Correlative Spiral experiment. The test area was a vertical plane, 16 km (A to B) by 1500 m altitude. Surface location, 0, and the orientation of plane A-B through 0 were selected on a day-to-day basis. The remote-sensor aircraft flight sequence was along leg AB, generally in the following sequence:

- (a) two constant altitude passes at 1350 m,
- (b) two constant altitude passes at 750 m, and
- (c) two constant altitude passes at 1350 m.

This flight sequence required about 45 minutes. Flight altitudes for the remote sensor were selected on a mission-by-mission basis. The in situ aircraft flight sequence consisted of constant altitude passes along C-D at 150 m altitude increments from 1500 m to 150 m and back to 1500 m with spirals between altitudes at C and D. Approximately 1 hour was required for completion of the flight sequence. The Correlative Spiral experiment was conducted four times during the SEV-UPS field program. Table II summarizes the test parameters for these flights. Figure 3 shows the geographical location of the various test areas with nearby surface  $O_3$  monitoring sites.

#### Correlative Box Face

Figure 4 illustrates a typical flight plan for the Correlative Box Face experiment. The test area was a vertical plane 30 to 40 km (A to B) by 1500 m altitude. Surface locations A and B were selected on a daily basis with a surface  $O_3$  monitoring site in the near vicinity. The flight plan for the remote-sensor aircraft consisted of repetitive (3) constant altitude traverses of leg AB, first at approximately 1350 m altitude and then at 750 m. Again approximately 45 minutes are required to complete the flight sequence and exact flight altitudes were selected on a mission basis. The in situ flight sequence consisted of

- (a) constant altitude (300 m) leg A to B (1 to 2, see fig. 4),
- (b) spiral at B from 300 m to 1500 m altitude (2 to 3),
- (c) constant rate of descent flight from B at 1500 m altitude to A at 300 m altitude (3 to 4),
- (d) spiral at A from 300 m to 1500 m altitude (4 to 5),
- (e) constant rate of descent flight from A at 1500 m altitude to B at 300 m altitude (5 to 6), and
- (f) constant altitude (300 m) leg from B to A (6 to 7).

Approximately 1 hour was required for this flight sequence. The Correlative Box Face experiment was conducted three times. Table III summarizes the test parameters for each flight. Figure 5 shows the geographical location for each flight.

## OZONE ACCURACY

As part of the SEV-UPS measurement activities, an extensive quality assurance effort was conducted with the ozone instruments onboard the NASA correlative in situ data aircraft. The program consisted of

- (1) premission multipoint laboratory calibration using EPA approved techniques,
- (2) single point, weekly calibration verification during the program,
- (3) mid-mission, multipoint audit by EPA certified auditor,
- (4) in-flight verification of any observed instrument problems, and
- (5) engineering flight experiments to compare measurements with other ozone monitoring platforms (aircraft and surface).

The appendix discusses the results of this effort and the effect on the reported ozone data. The results presented in the appendix show several inherent uncertainties in the UV absorption data taken onboard the NASA correlative in situ aircraft. While it is estimated that these uncertainties exceeded 20 ppb only about 30 percent of the time, the authors have chosen not to report the UV absorption data. No significant problems were noted with the chemiluminescent instrument and the ozone data presented in the following section were measured with this instrument. Based on the laboratory and quality assurance tests of this instrument, the data are accurate (absolute) to  $\pm 10$  percent or  $\pm 5$  ppb (whichever is the largest) with a repeatability of  $\pm 2$  or 3 percent or  $\pm 3$  ppb. In addition,  $O_3$  data presented from other monitoring platforms (aircraft and surface) are of the same order of accuracy and repeatability.

## CORRELATIVE DATA RESULTS

Several experiments were conducted during the 1979 SEV-UPS field program to provide in situ data for correlation with the LAS  $O_3$  remote sensor data. This section presents, in chronological order, that in situ data to be used in evaluation of the LAS performance. The measured data are presented in figures 6 through 27. Statistical results for some flight legs are shown in tables IV, V, and VI. Anticipated uses for the correlative data experiments and summary ozone data are given in tables VII and VIII, respectively.

### August 7, 1979, Eastville Morning Correlative Spiral Experiment

As shown in table II the experiment was conducted in the Eastville area from about 1045 to 1205 e.d.t. No significant deviations from the flight plans of figures 2 and 3 occurred. Figure 6 shows the temperature and dewpoint profiles for the test area. Shown are the average values computed from the constant altitude portions of the flight plan. Solid data points indicate a repeated value. Due to procedural errors onboard the aircraft data are not shown for the first four constant altitude passes (nominally 1500, 1350, 1200, and 1050 m). The data show little variation with time during the hour experiment.

The ozone data also showed little variation with time during the experiment. This is illustrated in figure 7, in which constant altitude (950 and 300 m) repetitive passes of leg C to D are shown. Table IV shows the average values and associated standard deviations for the constant altitude legs. For the repetitive passes at a given altitude, the ozone averages show close agreement: average of 3 ppb, maximum of 4 ppb, and minimum of 1 ppb difference. ( $\beta_{scat}$  and  $NO/NO_x$  aircraft

measurements also show little variation of these effluents as a function of time during the 1-hour experiment.) A close examination of figure 7, shows  $O_3$  concentrations along leg C to D to vary linearly, being about 15 ppb higher at D than C. This was observed for all constant altitude passes at 610 m and below. This is also seen from figure 8, which is a plot of the spiral data taken at points C and D as well as the average  $O_3$  (both passes) from table IV. As can be seen,  $O_3$  concentrations below about 800 m are consistently higher at point D than point C. Shown for reference on figure 8 are hourly averaged  $O_3$  concentrations at the Cheriton surface station (UV absorption instrument). The average  $O_3$  concentration from the surface to 1350 m is calculated to be  $74 \pm 7$  ppb. The error bar is due to the  $\pm 10$  percent uncertainty in the absolute accuracy of the  $O_3$  instrument. The average concentrations at other altitudes and over points C and D are given in table VIII.

#### August 7, 1979, Eastville Afternoon Correlative Spiral Experiment

The time of the afternoon flight was 1400 to 1445 e.d.t., at the same location as the morning flight. Only the first half of the flight (descent portion, figure 2) was flown. Due to a leak in the ethylene gas supply system to the chemiluminescent instrument, this detector was not operated during the flight. In addition, the  $NO/NO_x$  instrument was inoperative due to operator error. The UV absorption instrument did operate; however, as the result of the problems with this instrument (discussed in the appendix), the absence of  $NO/NO_x$  data (useful in identifying some of these problems), and the fact that only a portion of the flight plan was flown, an adequate documentation of existing  $O_3$  concentrations is not available. Therefore, no data from this experiment are presented.

#### August 8, 1979, Chesapeake Light Correlative Spiral Experiment

As shown in table II and figure 3, the experiment was conducted at the Chesapeake Light (Atlantic Ocean) from 1240 to 1340 e.d.t. No significant deviations from the flight plan occurred. Figure 9 shows the temperature and dewpoint profiles for the test area. Shown are the average values computed from the constant altitude portions of the flight plan. Solid data points indicate a repeated value. The data show little variation with time during the 1-hour experiment.

The ozone data for the experiment (figure 10) showed little variation of ozone with time or with location along leg C to D. Table V shows the average ozone values and associated standard deviations for the constant altitude legs. For the repetitive passes at a given altitude, the maximum difference in the ozone average is 11 ppb (620 m); the minimum, 0 ppb; and the average, 4 ppb. ( $\beta_{scat}$  and  $NO/NO_x$  aircraft measurements also show little variation of these effluents as a function of time or location along flight leg C to D.) Figure 11 shows the ozone data which are representative of the  $O_3$  profile in the test area. Shown are the spiral results at C and D and the average  $O_3$  (both passes) from table V. The hourly average ozone concentrations from the Chesapeake Light surface station (UV absorption instrument) are also shown in figure 11.

The decrease in  $O_3$  from 109 ppb at 150 m to 25 ppb at the surface is indicative of a low-lying surface inversion layer. The presence of such a layer cannot be confirmed using the measured temperature data since no aircraft

data were taken below 150 m and surface air temperatures were not recorded at the Chesapeake Light station during this period. It should be noted that low surface inversion layers over water masses are common during the summer months, and, in fact, have been identified a number of times during other SEV-UPS experiments. Since a low-lying surface inversion isolates the air mass within it, surface scavenging of  $O_3$  via turbulent mixing results in low levels of  $O_3$  at or near the surface. Assuming a linear variation in ozone from 150 m to the surface, the average concentration of  $O_3$  from the surface to 1350 m is  $84 \pm 8$  ppb. Average concentrations from other altitudes are given in table VIII.

#### August 9, 1979, Craddockville Correlative Spiral Experiment

The experiment was conducted in the Craddockville area from about 1300 to 1400 e.d.t. (see table II and figure 3). The planned flight schedule was followed, and after completion of this sequence, a continuous spiral from approximately 1500 to 150 m altitude was flown at point D. Figure 12 shows the temperature and dewpoint profiles for the test area. Shown are the average values computed from the constant altitude portion of the flight plan as well as the individual 10-second averages from the spiral performed at D after completion of the planned correlative flight. Shaded data points indicate repeated values. Notable features of the data are the repeatability of the profiles over the 1-hour duration of the experiment, and the temperature inversion and sharp dewpoint decrease indicating the mixing height at approximately 750 to 800 m altitude.

Little variation was observed in the ozone concentrations over the hour duration of the experiment or spatially along leg C to D (fig. 13). Table VI shows the average ozone values and standard deviations for each of the constant altitude legs. Again, for the repetitive passes at a given altitude, little variance in the ozone averages are observed; average difference is only 2 ppb. ( $\beta_{\text{scat}}$ ,  $NO$ , and  $NO_x$  measurements on the aircraft also show little variation of these effluents with time or location along leg C to D.) Figure 14 shows the ozone data which are representative of the  $O_3$  concentrations in the test area. Included in this figure are the data from the spiral portions of the flight plan (figure 2), the spiral at D at completion of the planned flight, and the ozone averages (both passes) from table VI. Also shown is the hourly average ozone concentration from the Wachapreague surface station (UV absorption instrument). Note that the ozone is uniformly mixed throughout the altitude range from the surface to the mixing height of 750 m. The average  $O_3$  concentration from the surface to 1350 m is  $78 \pm 8$  ppb. Values for other altitudes are given in table VIII.

#### August 16, 1979, Chesapeake Correlative Box Face Experiment

As shown in table III and figure 5, this experiment was conducted in the rural portions of the city of Chesapeake from about 1335 to 1435 e.d.t. The flight leg A to B was 40 km in length. Figure 15 shows the temperature and dewpoint profiles from the spirals at points A and B (figure 4). Most notable is the strong temperature inversion at about 1350 to 1400 meters (mixing height).

The ozone data (fig. 16) showed little change in concentrations over the 1-hour time period of the experiment. The average  $O_3$  level and standard deviations are  $64 \pm 4$  ppb (1335 to 1345 e.d.t. pass) and  $63 \pm 4$  ppb (1420 to 1432 e.d.t. pass). Figure 16 does show an approximately linear spatial variation of  $O_3$  along leg AB, with concentrations approximately 10 ppb higher at point B than point A. As shown in figure 17 (spiral data at points A and B), this variation is seen at approximately all altitudes below the mixing height of 1400 m.

Figure 18 shows the vertical distribution of  $O_3$  for the constant rate of descent legs B to A and A to B. Both figures 17 and 18 show that the distribution of  $O_3$  with altitude is essentially constant at A and B, but with about a 10 ppb linear difference between them. From 300 to 1400 m, the  $O_3$  average is calculated to be  $59 \pm 3$  ppb over A and  $69 \pm 3$  ppb over B. This 10 ppb difference is statistically significant at a 99 percent confidence level. Also shown in figures 17 and 18 are hourly averaged surface  $O_3$  values from 1300 to 1400 e.d.t. The value labelled C is an average of three sites (Tidewater Community College, Naval Air Station, and Virginia Agricultural Station) which are near point A and the value labeled D is from the Naval Communications Center near point B. The surface values are significantly lower than the aircraft values at 300 m. It was not possible to determine if a temperature inversion layer existed between the surface and 300 m. It is assumed that ozone varies linearly between the surface and 300 m, in which case the average  $O_3$  concentration to 1350 m is calculated to be 54 ppb at A and 64 ppb at B.

For correlative purposes for the LAS, the average  $O_3$  from the surface to 1350 m over the box face is  $59 \pm 6$  ppb. There is a 10 ppb linear variation between points A and B, varying from  $54 \pm 3$  to  $64 \pm 3$  ppb. These  $\pm 3$  ppb variances reflect the relative accuracy of the measurements.

#### August 17, 1979, West Point Correlative Box Face Experiment

As shown in table III and figure 5, this experiment was conducted in a rural area near West Point, Virginia, from 0950 to 1035 e.d.t. There were no significant deviations from the flight plan of figures 4 and 5, and the flight leg AB was 30 km in length. Figures 19 and 20 show temperature and dewpoint profiles for the test area. The profiles show significant variation in dewpoint as a function of time and location. Factors possibly affecting the dewpoint include a rising mixing height with time, some clouds in the test area, and pulp mill emissions approximately 15 km upwind of the test area (see fig. 5).

Figure 21 shows the ozone data for the constant altitude flights at 220 meters. Two points are immediately obvious from the data: (1) ozone levels are higher for the second pass, and (2) ozone concentrations vary considerably along leg AB. For the first pass, the average value of  $O_3$  is 44 ppb with a standard deviation of 10 ppb; for the second pass,  $53 \pm 7$  ppb. Along leg A to B, ozone concentrations vary as much as 40 ppb. The spatial variation of  $O_3$  along leg A to B is due mainly to emissions of the pulp mill. As shown in the insert to figure 21, a sizable plume was detected by the nephelometer approximately midway of leg AB.  $\beta_{scat}$  increases by about a factor of 20 (0950 to 0959 pass), while  $O_3$  decreased about 20 ppb and NO and  $NO_x$  increased 15 to 20 ppb. The locations of the observed plume along leg AB and the pulp mill were consistent with the wind flow from the north. The exact spatial extent of this plume on the effluent concentrations along

leg AB may extend beyond the well defined plume boundaries. For example, it is noted that for the 0950 to 0959 pass of figure 21, the effluent concentrations from point A to the edge of the plume are significantly different than those from the other edge of the plume to B. On the A side of the plume, effluent averages and the associated standard deviations are:  $O_3 = 51 \pm 9$  ppb,  $NO = 19 \pm 2$  ppb, and  $NO_x = 31 \pm 3$  ppb. On the B side, effluent averages are  $O_3 = 37 \pm 6$  ppb,  $NO = 30 \pm 7$  ppb, and  $NO_x = 57 \pm 8$  ppb.

Figures 22 and 23 show  $O_3$  profiles for the test area. Also shown are the hourly averaged ozone from the Milford Haven (UV absorption instrument) surface station. As shown by the data, the lower altitude ozone levels are lower at point B than at point A. Figure 24 is an envelope plot of the data extremities of figures 22 and 23. The average  $O_3$  concentration from the surface to 1350 m, calculated from midpoints of the data envelope is  $63 \pm 6$  ppb. Values at other altitudes are given in table VIII. If it is assumed that the 20 ppb  $O_3$  depletion within the plume boundaries is constant throughout the mixing height, the average  $O_3$  concentration of a column that includes the plume is 46 ppb at 750 m, 51 ppb at 1050 m, and 55 ppb at 1350 m.

#### August 23, 1979, Surry Correlative Box Face Experiment

As shown in table III and figure 5, this experiment was mostly conducted over Surry County from about 1315 to 1420 e.d.t. The flight leg A to B was 37 km in length. The in situ data for this experiment were obtained onboard another aircraft. The aircraft was outfitted similarly to that of the NASA Cessna 402 ( $O_3$ , NO,  $NO_x$ ,  $\beta_{scat}$ , dewpoint, temperature, and flight parameters) and was operated by Research Triangle Institute (RTI) under contract to NASA. The aircraft was a twin engine Navajo B and is described in detail in reference 7. Figure 25 shows the temperature and dewpoint profiles from the spirals at points A and B. Notable features are the apparent temperature inversion at about 700 to 800 meters, and the possibility of a few clouds at point A (600 to 1000 m altitude) as indicated by equal dewpoint and temperature values in the profile at point A. Temperature and dewpoint profiles from the constant rate of descent portions of the flight plan show similar results; however, no evidence of clouds is noted.

The ozone data show little variation in concentrations along leg AB or over the 1-hour duration of the flight (fig. 26). The average  $O_3$  level and standard deviations for the passes are  $70 \pm 5$  ppb (1314 to 1322 pass) and  $68 \pm 4$  ppb (1405 to 1415 pass). Figure 27 is an envelope of ozone profiles obtained during the flight. Four sets of data are included from 1322 to 1405 e.d.t.: spiral at A, spiral at B, constant descent leg A to B, and constant descent leg B to A. Little variation in  $O_3$  with altitude is noted. In addition, the envelope is narrow (maximum of 15 ppb) supporting the earlier conclusion that  $O_3$  is not significantly varying in the test area. Surface  $O_3$  hourly averages at the nearest surface site (NASA Langley, see figure 5) are also shown from 1100 to 1200 and 1400 to 1500 e.d.t. Surface data are not available from 1200 to 1400 e.d.t. at the site. The average concentration of  $O_3$  from the surface to 1350 m is  $65 \pm 7$  ppb. Values at other altitudes are given in table VIII.

#### CONCLUDING REMARKS

As part of the SEV-UPS summer field program, seven experiments were conducted to provide in situ ozone data for evaluation of the Laser Absorption Spectrometer ozone remote sensor (accuracy, repeatability, and operational characteristics). Of the seven experiments, six provided usable in situ ozone data from which the basic accuracy and repeatability of the LAS can be evaluated. In addition, observed small changes (10 ppb for example) in ozone concentrations as a function of time and/or location along a flight leg, should be useful in assessing the lower limits of the remote sensor for detection of ozone fluctuations. Table VII summarizes the anticipated uses of the data from the six experiments.

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## APPENDIX

### OZONE INSTRUMENT CALIBRATION AND CHARACTERIZATION

As discussed earlier, the in situ aircraft monitored ozone using two techniques: UV absorption and chemiluminescence. In many cases, the two measurement techniques did not agree as to the absolute values of the existing concentrations. On the average, it is estimated that 40 percent of the time agreement was within about 10 ppb; 30 percent of the time, instrument disagreement was within 10 to 20 ppb; and about 30 percent of the time, instrument disagreement was greater than 20 ppb. Based upon ozone calibration uncertainties (10 percent absolute accuracy and 2 to 3 percent precision) and typical field audit experience with in situ  $O_3$  instrumentation onboard aircraft platforms, instrument agreement can be expected to be within 10 ppb or 10 percent. Considerable time and planning went into the SEV-UPS program in areas of instrument calibration, operation, and quality assurance for purposes of providing a data base to investigate measurement inconsistencies. This section discusses the results of this quality assurance program as applied to the ozone measurements onboard the in situ aircraft.

#### Calibration

Both ozone detectors were calibrated on contract (NAS1-15827, Research Triangle Institute) in accordance with procedures specified by the Environmental Protection Agency (ref. 8). The same calibration system, procedures, and personnel calibrated both units. Briefly, in this procedure a source of zero gas was passed through a quartz tube and over a mercury vapor lamp to produce stable ozone concentrations. These concentrations were assayed by a UV absorption ozone analyzer that was modified for use as a calibration standard and intercompared with a reference UV photometer at the Environmental Protection Agency central laboratories in the Research Triangle Park, North Carolina. These assayed ozone concentrations were then injected directly into the two detectors. A voltage-concentration calibration curve was obtained by linear regression of the multipoint (5 in this case) calibration data. The correlation coefficient for the linear regression analysis of the calibration data of both instruments was 0.999.

During the first flights of the in situ aircraft, it was observed that the chemiluminescent instrument calibration curve was in error. The instrument was recalibrated by NASA using an ozone generator previously calibrated in the laboratory (1 point at 100 ppb). Shortly thereafter, during the audit of the aircraft instruments (RTI, NAS-15827), a multipoint audit confirmed the NASA calibration. The NASA calibration and audit data provided the necessary calibration constants for the data reduction of the previously and subsequently obtained chemiluminescent data. The cause of the calibration change was not identified. The calibration change apparently occurred prior to installation of the instrument onboard the aircraft; additional checks during the field program showed no further calibration changes for the  $O_3$  instruments.

In addition to the basic calibration data, each of the ozone instruments was tested in an altitude simulation chamber (ref. 9) to define instrument behavior as a function of altitude (pressure effects) to a simulated altitude of 7500 m. All ozone data were corrected for altitude based on the data of reference 9.

## APPENDIX

### Audits

As part of the SEV-UPS quality assurance, each ozone instrument onboard the aircraft was audited during the field program. These audits were performed using field procedures similar to those discussed above in the Calibration section. Based on the calibration equation used in the data reduction, the response to a 100 ppb audit concentration was 99 ppb and 97 ppb for the UV absorption and chemiluminescent instruments, respectively. A linear regression analysis of the multipoint audit for each instrument resulted in a correlation coefficient of 0.998.

### Observations of Ozone Instrument Behavior

In the data reduction of the ozone data several instrument operational problems for the two ozone instruments were observed. The only significant observation concerning the chemiluminescent detector was the change in calibration coefficient of the instrument (already discussed) believed to have occurred between calibration by the contractor and installation onboard the aircraft. However, for the UV absorption instrument three recurring problems were noted: random zero shifts, particulate interference, and moisture interference.

Zero Shift - During the SEV-UPS measurement program, it was noted that the UV absorption and chemiluminescent instruments agreed sometime, but at other times significantly disagreed. In addition, it was noted that the UV absorption instrument would indicate ozone variations over short periods of time (1 minute) that were not detected by the chemiluminescent instrument, nor verified by other supporting instrumentation (NO/NO<sub>x</sub>,  $\beta$ scat) onboard the aircraft, and in some cases not consistent with the known photochemical production processes for O<sub>3</sub>. A series of inflight tests of both ozone instruments showed the UV absorption instrument to have a zero stability problem. This problem appeared to occur randomly, and based on the inflight zero gas tests, resulted in ozone concentrations as much as 10 ppb too low to 30 ppb too high. At times, the instrument zero would change several times during a flight (3 hours); at other times, it would remain constant for a flight but be different from that of the preceding day. The cause of the zero problem has not yet been determined.

Figure A-1 is typical of the inflight test illustrating the zero shifts. At the time indicated in the figure, a zero filter (charcoal) was placed on the instrument inlet connection (rear of instrument, using approximately 1-m length of teflon tubing) and the output of the instrument observed for approximately 5 minutes in this case. As shown by the figure, (after allowing for transients associated with filter installation, approximately 1 min.) the zero level ranges from a low of 9 ppb to a high of 25 ppb. On the average during the zero test, the zero level was 18 ppb. Based on the instrument calibration and audit, the zero response should be 0 ppb  $\pm$  a few ppb.

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Table A-I summarizes the results of zero tests. It was generally noted that when the two  $O_3$  instruments differed, the UV absorption instrument indicated the higher  $O_3$  value. This observation is consistent with the data of table A-I. The same charcoal filter test was applied to the chemiluminescent instrument with a typical response as shown in figure A-2. In addition, the ability of the filter to scrub  $O_3$  was tested at two surface locations, which showed that the filter did adequately scrub  $O_3$  from the sample stream.

Particulate Interference - Particulate interference was observed to be affecting the UV absorption measurement data. This is a suspected interference for the UV absorption measurement. No particulate inlet filter was used in the aircraft sample system. The particulate interference results in an increased sensor output (higher  $O_3$  indication) in areas of high particulate concentrations. The interference is most pronounced in source plumes, for example powerplants. Figure A-3 illustrates the particulate interference problem and shows UV absorption  $O_3$ , nephelometer  $\beta_{scat}$ , and chemiluminescent  $O_3$  data. These data are a 13 km-downwind sampling of a pulp mill stack plume at about 300 m altitude. As noted in the figure, the nephelometer and UV absorption  $O_3$  responses are similar which indicates the interference of particulates with the UV absorption instrument. As shown by the chemiluminescent  $O_3$  data, the plume is deficient in  $O_3$  (compared to ambient). This is verified by the  $NO/NO_x$  data in the plume which show about a 20 ppb increase above ambient. While the particulate interference was most noted when the aircraft encountered a stack plume, at times the interference was apparent (lesser degree) as the aircraft penetrated the mixing layer. Analysis of the  $\beta_{scat}$  and  $NO/NO_x$  data can identify those times for which the UV absorption  $O_3$  data are suspect. However, correction of the data to account for the particulate interferences is not possible.

Moisture Interference - Moisture can also interfere with the UV absorption  $O_3$  measurement resulting in higher than normal instrument output. This effect was frequently noted in flights through clouds and transitions between layers of relatively dry and moist air. Figure A-4 illustrates the moisture interference showing data for a penetration through the mixing layer in the vicinity of clouds. Both  $O_3$  measurements,  $\beta_{scat}$ , temperature, and dewpoint data are shown. The similarity of the UV absorption  $O_3$ , dewpoint, and  $\beta_{scat}$  measurements are obvious.

All three problems with the UV absorption  $O_3$  measurements result in higher values than actually exist. As will be shown in the following section in which the Cessna aircraft  $O_3$  measurements are compared with other measurements, the UV absorption data are generally equal to or greater than the other results.

## APPENDIX

### In Situ Aircraft Ozone Data Comparisons

During the 4-week, SEV-UPS field program, numerous opportunities were available to compare the ozone measurements of the Cessna aircraft with other ozone measurements from surface stations and other participating aircraft. In some cases the data are from experiments flown specifically for these comparisons. In these cases, Cessna aircraft flights were within 2 km of the surface sites and wing-tip to wing-tip with the other aircraft. For those cases where the data are not from comparison experiments, the comparison data are from the site nearest to the Cessna location. Figure A-5 shows the comparison locations. Table A-II shows the comparison data.

Several comments are in order.

1. All ozone instruments (surface and aircraft) performed satisfactorily during the SEV-UPS audits. Using the audit concentrations as the "standard," all  $O_3$  instruments showed an absolute accuracy to within 10 percent of the audit standard.
2. Based on calibration techniques for ozone, an absolute accuracy of about 10 percent is typically expected. Instrument repeatability should be within a few percent. Lower limits on absolute accuracy and repeatability are approximately 5 ppb and 2 to 3 ppb, respectively.
3. Conclusions drawn from comparison of aircraft (including low altitude) data with surface stations must be carefully prepared. Due to surface scavenging of ozone, steep  $O_3$  gradients may exist in the lower 100 meters. In general, surface and aircraft comparisons are to be considered qualitatively; i.e., surface and airborne concentrations should be in the same range, and generally surface values should be lower.

From the surface and Cessna comparisons of table A-II(a), the following are noted;

1. For the Cessna chemiluminescent data, reported  $O_3$  measurements were within 0 to 5 ppb of the nearest surface station in 8 percent (1 of 13) of the comparisons; 6 to 10 ppb, 23 percent; 11 to 15 ppb, 8 percent, 16 to 20 ppb, 23 percent; and greater than 20 ppb, 38 percent of the comparisons. In all cases the aircraft measurements were higher..
2. For the Cessna UV absorption data, reported  $O_3$  measurements were within 0 to 5 ppb of the nearest surface station 0 percent; 6 to 10 ppb, 15 percent; 11 to 15 ppb, 8 percent; 16 ppb to 20 ppb, 8 percent; and greater than 20 ppb, 69 percent. Again, all aircraft measurements were higher.
3. In all but two comparison cases, the chemiluminescent instrument reports a value closer to the surface station value than the UV absorption instrument.

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4. For those two experiments specifically for comparison of aircraft and surface data (Aug. 15 and Aug. 29), the chemiluminescent technique agreed better with the surface stations or as good as the UV absorption technique.

From the aircraft-Cessna comparisons of table A-II(b), the following are noted:

1. For the Cessna chemiluminescent data, reported  $O_3$  measurements were within 6 to 10 ppb of the other aircraft results, 50 percent (2 of 4); and 11 to 15 ppb, 50 percent.
2. The same comparison for the UV absorption data is: 0 to 5 ppb 75 percent; and 11 to 15 ppb, 25 percent.
3. For all comparisons, both Cessna instruments are within expected absolute accuracy assuming a 10 percent absolute uncertainty on all aircraft  $O_3$  measurements.

### Summary

In summary, the data presented in this section show several inherent problems or uncertainties in the UV absorption data taken onboard the Cessna aircraft. Two problems were in the area of interferences, and in some cases, times of occurrence can be determined by inspection of other data onboard the aircraft. However, the third problem (zero shift) occurs randomly and cannot be identified as to when it occurs and what is the true zero level. In general, in the comparison of the two  $O_3$  instruments onboard the aircraft with other  $O_3$  measurements, the chemiluminescent measurements agree more frequently. In those cases where this is not the case, the chemiluminescent measurement is still within the expected 10 percent uncertainty of calibration. Based on these observations, the chemiluminescent instrument is the more consistent and, hence, generally the more accurate  $O_3$  measurement made onboard the aircraft. For purposes of providing data for comparison with the remote sensor, only the chemiluminescent data are considered. The ozone data presented in the report are the chemiluminescent data.

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TABLE A-I - Summary of Zero Checks of UV Absorption Ozone Instrument

| Test Duration <sup>1</sup><br>(min) | Instrument Time <sup>2</sup><br>(min) | Zero<br>avg <sup>4</sup> | Reading <sup>3</sup><br>max <sup>4</sup> | ppb<br>min <sup>4</sup> |
|-------------------------------------|---------------------------------------|--------------------------|--|-------------------------|
| 6                                   | 86                                    | 27                       | 32                                       | 18                      |
| 4                                   | 142                                   | 24                       | 27                                       | 9                       |
| 4                                   | 216                                   | 18                       | 25                                       | 9                       |
| 25                                  | -0-                                   | 16                       | 22                                       | 8                       |
| 7                                   | 102                                   | 3                        | 8  | -4                      |
| 4                                   | 164                                   | 24                       | 29                                       | 20                      |
| 8                                   | 204                                   | 13                       | 22                                       | 3                       |
| 10                                  | 75                                    | -3                       | -0-                                      | -9                      |

## NOTES:

1 - duration of filter test.

2 - continuous operating time of instrument prior to filter test.

3 - reading based on calibration used in data reduction.

4 - values after allowing for filter equilibrium; i.e., values computed from data of last half of filter test.

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TABLE A-II - Ozone Comparisons

## a. Surface Site Comparisons

| Date                | Surface Data                    |                  |                             | Cessna Data      |                 |                    | ozone, ppb <sup>1</sup><br>UV | chem |
|---------------------|---------------------------------|------------------|-----------------------------|------------------|-----------------|--------------------|-------------------------------|------|
|                     | surface location                | time<br>(e.d.t.) | ozone <sup>6</sup><br>(ppb) | time<br>(e.d.t.) | altitude<br>(m) |                    |                               |      |
| Aug 7               | Cheriton                        | 1100-1200        | 64                          | 1122-1125        | 120             | 84                 | 72                            |      |
| Aug 7               | Cheriton                        | 1400-1500        | 59                          | 1443-1445        | 120             | 128                | NA <sup>2</sup>               |      |
| AUG 9               | Wachapreague                    | 1300-1400        | 87                          | 1332-1334        | 120             | 98                 | 91                            |      |
| Aug 15              | Communication Center            | 0700-0900        | 28                          | 0840-0844        | 150             | 73                 | 36                            |      |
| Aug 15 <sup>3</sup> | Chesapeake Light <sup>4</sup>   | 1200-1300        | 55                          | 1445-1453        | 50              | 80                 | 79                            |      |
|                     |                                 | 1500-1600        | 39                          |                  |                 |                    |                               |      |
|                     | Communication Center            | 1500-1600        | 72                          | 1517-1525        | 100             | 95                 | 87                            |      |
|                     | Navy Base                       | 1500-1600        | 46                          | 1540-1550        | Surface         | 97                 | 74                            |      |
|                     | NASA                            | 1500-1600        | 71                          | 1558-1607        | Surface         | 102                | 79                            |      |
| Aug 16              | Chesapeake Airport <sup>4</sup> | 1200-1300        | 40                          | 1334-1344        | 200             | NA <sup>2</sup>    | 64                            |      |
|                     |                                 | 1500-1600        | 45                          | 1420-1432        | 200             |                    |                               |      |
| Aug 20              | Wachapreague                    | 1100-1200        | 62                          | 1135-1145        | 150             | 75                 | 88                            |      |
| Aug 29 <sup>3</sup> | Communication Center            | 1000-1100        | 24                          | 1035-1045        | 60              | 24-41 <sup>5</sup> | 42                            |      |
|                     |                                 | 1100-1200        | 17                          | 1123-1131        | Surface         |                    |                               |      |

b. Aircraft Comparisons<sup>3</sup>

| Date   | Comparison Aircraft Data |                 |                  |                             | Cessna Data     |                  |                                 |        |
|--------|--------------------------|-----------------|------------------|-----------------------------|-----------------|------------------|---------------------------------|--------|
|        | platform                 | altitude<br>(m) | time<br>(e.d.t.) | ozone <sup>7</sup><br>(ppb) | altitude<br>(m) | time<br>(e.d.t.) | ozone, ppb <sup>1,7</sup><br>UV | chem   |
| Aug 15 | NASA C-54                | 1500            | 1018-1025        | 62 ± 3                      | 1550            | 1019-1027        | 59 ± 4                          | 54 ± 5 |
|        | NASA C-54                | 600             | 1037-1044        | 55 ± 3                      |                 |                  |                                 |        |
| Aug 20 | RTI Navajo               | 1580            | 1112-1122        | 72 ± 1                      | 1600            | 1112-1122        | 75 ± 18                         | 86 ± 2 |
|        | RTI Navajo               | 250             | 1135-1145        | 76 ± 9                      |                 |                  |                                 |        |

<sup>1</sup> UV ≡ UV absorption instrument; chem ≡ chemiluminescent instrument<sup>2</sup> instrument not operating<sup>3</sup> experiment designed for surface site comparison, or aircraft comparison<sup>4</sup> surface data not available 1300 to 1500 e.d.t.<sup>5</sup> range of variation for two passes<sup>6</sup> 1 hour average<sup>7</sup> average ± standard deviation

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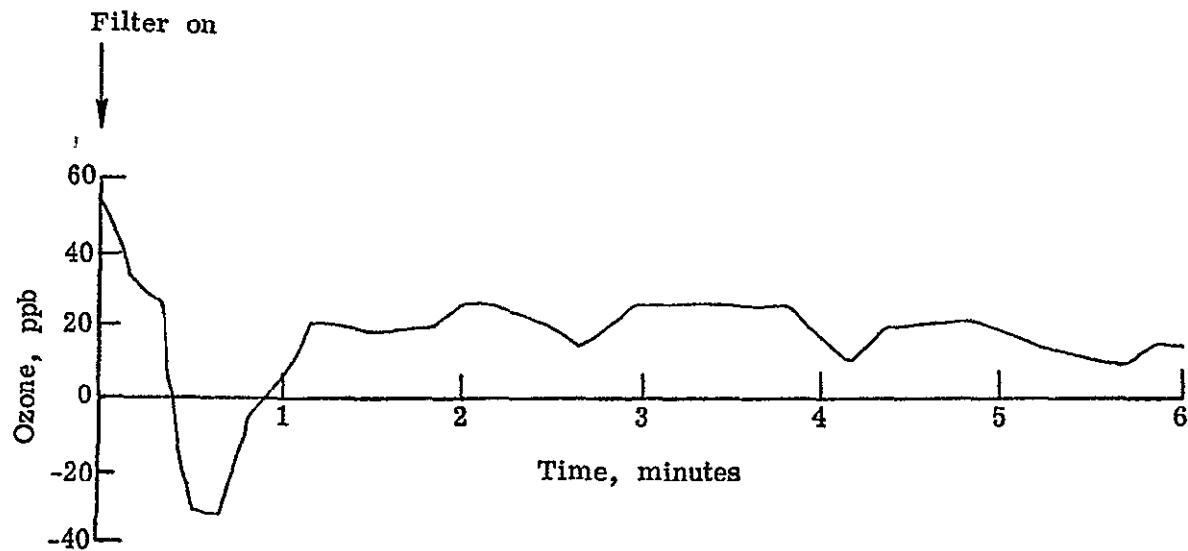


Figure A-1 - Typical results of zero filter tests of ozone UV absorption instrument.

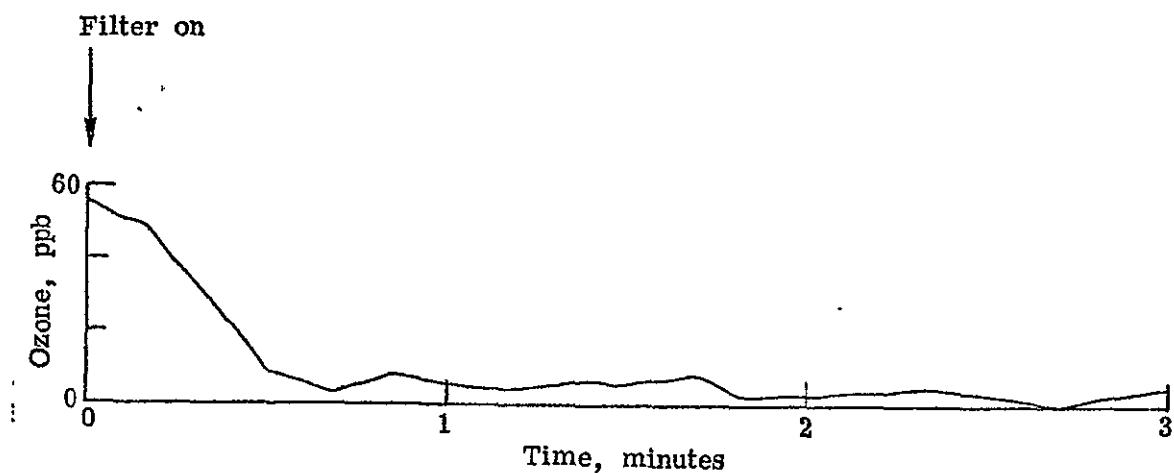


Figure A-2 - Typical results of zero filter tests of ozone chemiluminescent instrument.

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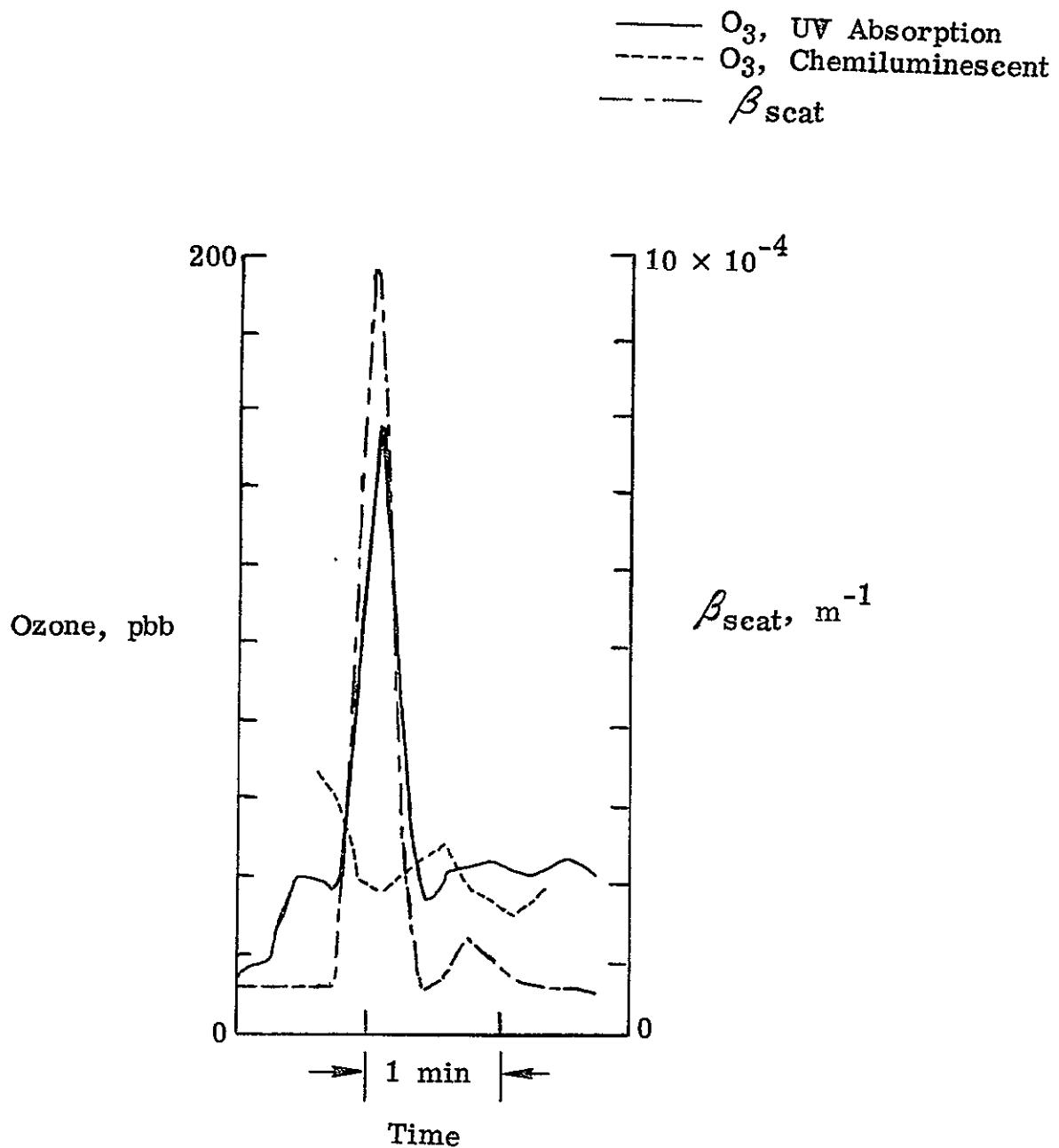


Figure A-3 - Data illustrating particulate interference with UV absorption ozone measurement.

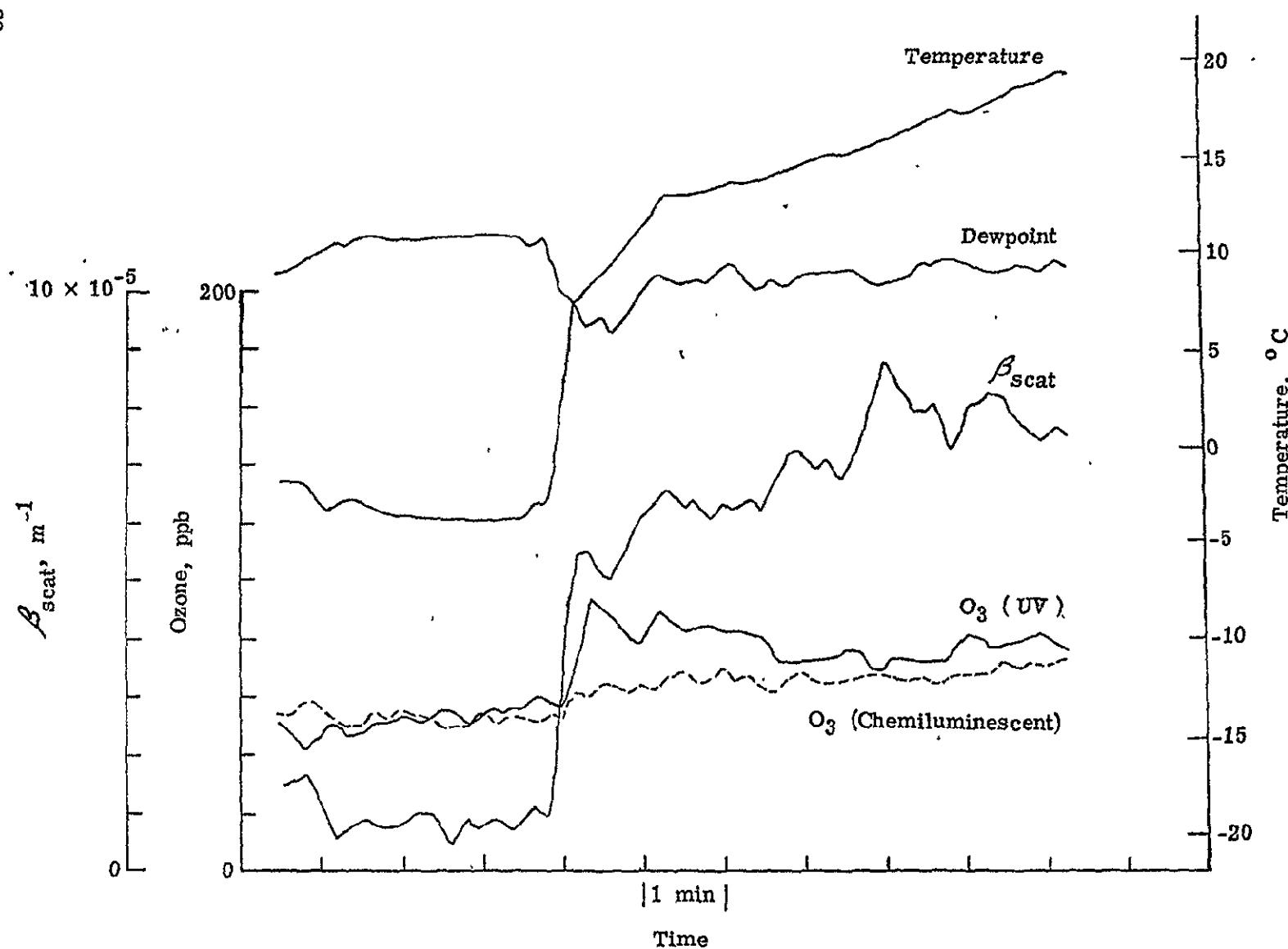


Figure A-4 - Data illustrating moisture interference with UV absorption ozone measurement.

APPENDIX

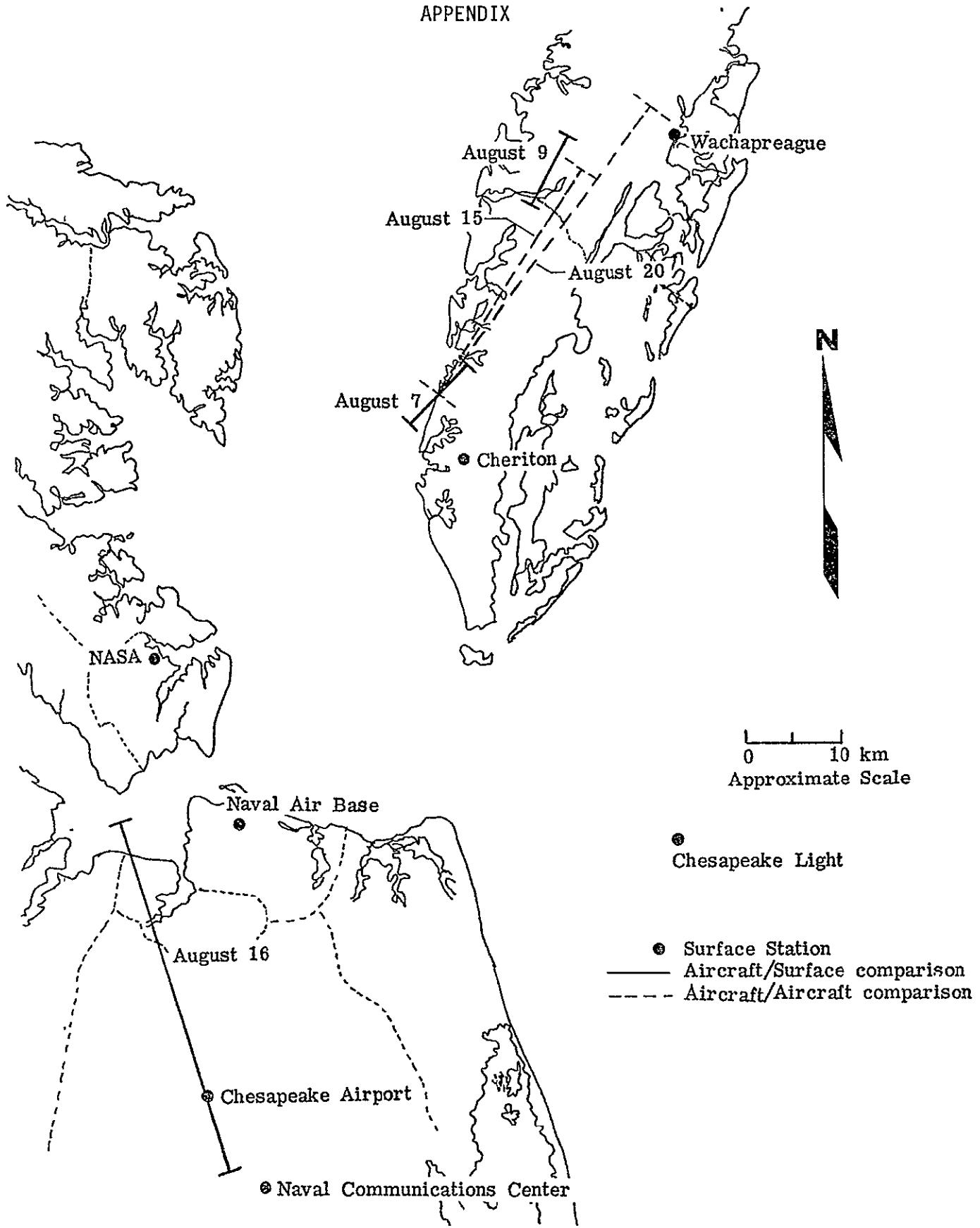


Figure A-5 - Ozone comparison measurement locations.

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TABLE I - In Situ Aircraft Instrumentation

| Measured Parameter     | Principle        | Range/detection limit   | Reference <sup>1</sup> |
|------------------------|------------------|---|------------------------|
| O <sub>3</sub>         | chemiluminescent | 0 to 250 ppb/5 ppb  | 6                      |
| O <sub>3</sub>         | UV absorption    | 0 to 300 ppb/5 ppb  | 1                      |
| NO and NO <sub>x</sub> | chemiluminescent | 0 to 200 ppb/5 ppb  | 5                      |
| scat                   | nephelometer     | 0 to 10 <sup>-3</sup> m <sup>-1</sup> /10 <sup>-5</sup> m <sup>-1</sup> | 5                      |
| temperature            | resistance       | -30 to 30°C/0.1 °C  | 5                      |
| dewpoint               | cooled mirror    | -100 to 100°/0.1°C  | 5                      |

1 - see references at end of text

TABLE II - Test Data for Correlative Spiral Experiment

| Date/Location           | Time (e.d.t.) | VOR <sup>1</sup> | Radial/distance from VOR <sup>2</sup> | point 0 | point A | point B | point C | point D |
|-------------------------|---------------|------------------|---------------------------------------|---------|---------|---------|---------|---------|
| 3 Aug 7/<br>Eastville   | 1045-1205     | Cape Charles     | 0°/0                                  | 220°/8  | 40°/8   | 220°/4  | 40°/4   |         |
| Aug 8/<br>Chesa. Light  | 1240-1340     | Norfolk          | Chesa.<br>Light                       | 95°/34  | 95°/50  | 95°/38  | 95°/46  |         |
| Aug 9/<br>Craddockville | 1300-1400     | Cape Charles     | 35°/28                                | 35°/20  | 35°/36  | 35°/24  | 35°/32  |         |

1 - Aircraft VOR station (see figure 3)

2 - degrees/kilometer from VOR station; see figure 2 for point designation

3 - two experiments at same locations (morning and afternoon)

TABLE III - Test Data for Correlative Box Face

| Date   | Approximate Location | Time (e.d.t.) | VOR <sup>1</sup> | Radial/distance from VOR <sup>2</sup> |         |
|--------|----------------------|---------------|------------------|---------------------------------------|---------|
|        |                      |               |                  | Point A                               | Point B |
| Aug 16 | Chesapeake           | 1335-1435     | Elizabeth City   | 350°/78                               | 350°/38 |
| Aug 17 | West Point           | 0950-1035     | Harcum           | 110°/10                               | 290°/20 |
| Aug 23 | Surry                | 1315-1420     | Franklin         | 35°/57                                | 35°/20  |

1 - Aircraft VOR station (see figure 5)

2 - degrees/kilometer from VOR station; see figure 4 for point designation

TABLE IV - Ozone Averages, Constant Altitude Legs: August 7, 1979, Eastville Morning Correlative Spiral

| Altitude (m) | Average Concentration $\pm$ standard deviation, ppb |             |             |
|--------------|---|-------------|-------------|
|              | First Pass  | Second Pass | Both Passes |
| 1600         | -   | 79 $\pm$ 1  | -           |
| 1450         | -   | 81 $\pm$ 2  | -           |
| 1300         | -   | 82 $\pm$ 1  | -           |
| 1130         | -   | 76 $\pm$ 4  | -           |
| 950          | 83 $\pm$ 2  | 79 $\pm$ 1  | 81 $\pm$ 3  |
| 800          | 73 $\pm$ 2  | 76 $\pm$ 4  | 75 $\pm$ 4  |
| 610          | 72 $\pm$ 3  | 76 $\pm$ 3  | 74 $\pm$ 4  |
| 460          | 71 $\pm$ 3  | 74 $\pm$ 3  | 73 $\pm$ 3  |
| 290          | 73 $\pm$ 3  | 74 $\pm$ 4  | 73 $\pm$ 4  |
| 120          | 72 $\pm$ 3  | --          | --          |

TABLE V - Ozone Averages, Constant Altitude Legs: August 8, 1979, Chesapeake Light Correlative Spiral

| Altitude<br>(m) | Average Concentration ± standard deviation, ppb |             |             |
|-----------------|---|-------------|-------------|
|                 | First Pass                                      | Second Pass | Both Passes |
| 1600            | 66 ± 3  | 64 ± 2      | 65 ± 3      |
| 1430            | 67 ± 3  | 65 ± 3      | 66 ± 3      |
| 1280            | 71 ± 2  | 69 ± 2      | 70 ± 2      |
| 1110            | 77 ± 2  | 75 ± 1      | 76 ± 2      |
| 950             | 81 ± 1  | 78 ± 2      | 80 ± 3      |
| 780             | 92 ± 3  | 100 ± 3     | 95 ± 5      |
| 620             | 94 ± 3  | 105 ± 3     | 100 ± 6     |
| 450             | 107 ± 1   | 110 ± 3     | 109 ± 2     |
| 300             | 96 ± 3  | 96 ± 1      | 96 ± 3      |
| 150             | 109 ± 7   | -----       | -----       |

TABLE VI - Ozone Averages, Constant Altitude Legs: August 9, 1979, Craddockville Correlative Spiral

| Altitude<br>(m) | Average Concentration ± standard deviation, ppb |             |             |
|-----------------|---|-------------|-------------|
|                 | First Pass                                      | Second Pass | Both Passes |
| 1570            | 74 ± 2  | 73 ± 2      | 74 ± 2      |
| 1400            | 72 ± 2  | 70 ± 3      | 71 ± 3      |
| 1240            | 60 ± 2  | 56 ± 3      | 58 ± 3      |
| 1070            | 56 ± 1  | 60 ± 2      | 58 ± 3      |
| 910             | 64 ± 3  | 64 ± 3      | 64 ± 3      |
| 750             | 82 ± 2  | 78 ± 3      | 80 ± 3      |
| 590             | 87 ± 1  | 87 ± 2      | 87 ± 2      |
| 430             | 91 ± 1  | 90 ± 2      | 91 ± 2      |
| 260             | 89 ± 1  | 88 ± 2      | 88 ± 2      |
| 120             | 91 ± 2  | -----       | -----       |

TABLE VII - Summary of Potential Uses of Correlative Data Experiments,  
SEV-UPS 1979

| Date      | Basic Instrument<br>Accuracy/Repeatability | Detection of small O <sub>3</sub> changes |         |       |
|-----------|--|---|---------|-------|
|           |  | Time                                      | Spatial | Plume |
| August 7  | Yes  | No  | Yes     | No    |
| August 8  | Yes  | No  | No      | No    |
| August 9  | Yes  | No  | No      | No    |
| August 16 | Yes  | No  | Yes     | No    |
| August 17 | Yes  | Yes                                       | Yes     | Yes   |
| August 23 | Yes  | No  | No      | No    |

TABLE VIII - Summary Table of Calculated Ozone: In Situ Data

## a. Ozone Concentration as Function of Altitude

| Altitude, m | Date<br>Location | Morning<br>Aug. 7 |    |    | 8   | 9   | 16  |    |    | 17  |    |    | 23  |
|-------------|------------------|-------------------|----|----|-----|-----|-----|----|----|-----|----|----|-----|
|             |                  | Mid               | C  | D  | Mid | Mid | Mid | A  | B  | Mid | A  | B  | Mid |
| 0           |                  | 64                | 64 | 64 | 28  | 88  | 41  | 36 | 45 | 48  | 48 | 48 | 62  |
| 150         |                  | 71                | 64 | 80 | 109 | 91  | 55  | 50 | 60 | 51  | 47 | 54 | 62  |
| 300         |                  | 73                | 68 | 80 | 96  | 89  | 64  | 59 | 69 | 54  | 48 | 59 | 64  |
| 450         |                  | 73                | 67 | 77 | 109 | 91  | 64  | 59 | 69 | 63  | 63 | 63 | 65  |
| 600         |                  | 74                | 67 | 82 | 100 | 87  | 64  | 59 | 69 | 69  | 69 | 69 | 65  |
| 750         |                  | 72                | 66 | 74 | 95  | 80  | 64  | 59 | 69 | 69  | 69 | 69 | 67  |
| 900         |                  | 81                | 81 | 81 | 84  | 64  | 64  | 59 | 69 | 68  | 68 | 68 | 67  |
| 1050        |                  | 78                | 78 | 78 | 76  | 58  | 64  | 59 | 69 | 69  | 69 | 69 | 66  |
| 1200        |                  | 78                | 78 | 78 | 72  | 58  | 64  | 59 | 69 | 71  | 71 | 71 | 66  |
| 1350        |                  | 80                | 80 | 80 | 67  | 69  | 64  | 59 | 69 | 71  | 71 | 71 | 70  |

## b. Altitude Average Ozone Concentration

| Altitude<br>Range, m | Date<br>Location | Morning<br>Aug. 7 |    |    | 8   | 9   | 16  |    |    | 17  |    |    | 23  |
|----------------------|------------------|-------------------|----|----|-----|-----|-----|----|----|-----|----|----|-----|
|                      |                  | Mid               | C  | D  | Mid | Mid | Mid | A  | B  | Mid | A  | B  | Mid |
| 0-750                |                  | 71                | 66 | 76 | 90  | 88  | 59  | 54 | 64 | 59  | 57 | 60 | 64  |
| 0-1050               |                  | 73                | 70 | 77 | 87  | 81  | 60  | 55 | 65 | 61  | 60 | 62 | 65  |
| 0-1350               |                  | 74                | 71 | 77 | 84  | 78  | 61  | 56 | 66 | 63  | 62 | 64 | 65  |
| 750-1050             |                  | 77                | 75 | 78 | 85  | 67  | 64  | 59 | 69 | 69  | 69 | 69 | 67  |
| 750-1350             |                  | 78                | 77 | 78 | 79  | 66  | 64  | 59 | 69 | 70  | 70 | 70 | 67  |
| 1050-1350            |                  | 79                | 79 | 79 | 72  | 62  | 64  | 59 | 69 | 70  | 70 | 70 | 67  |

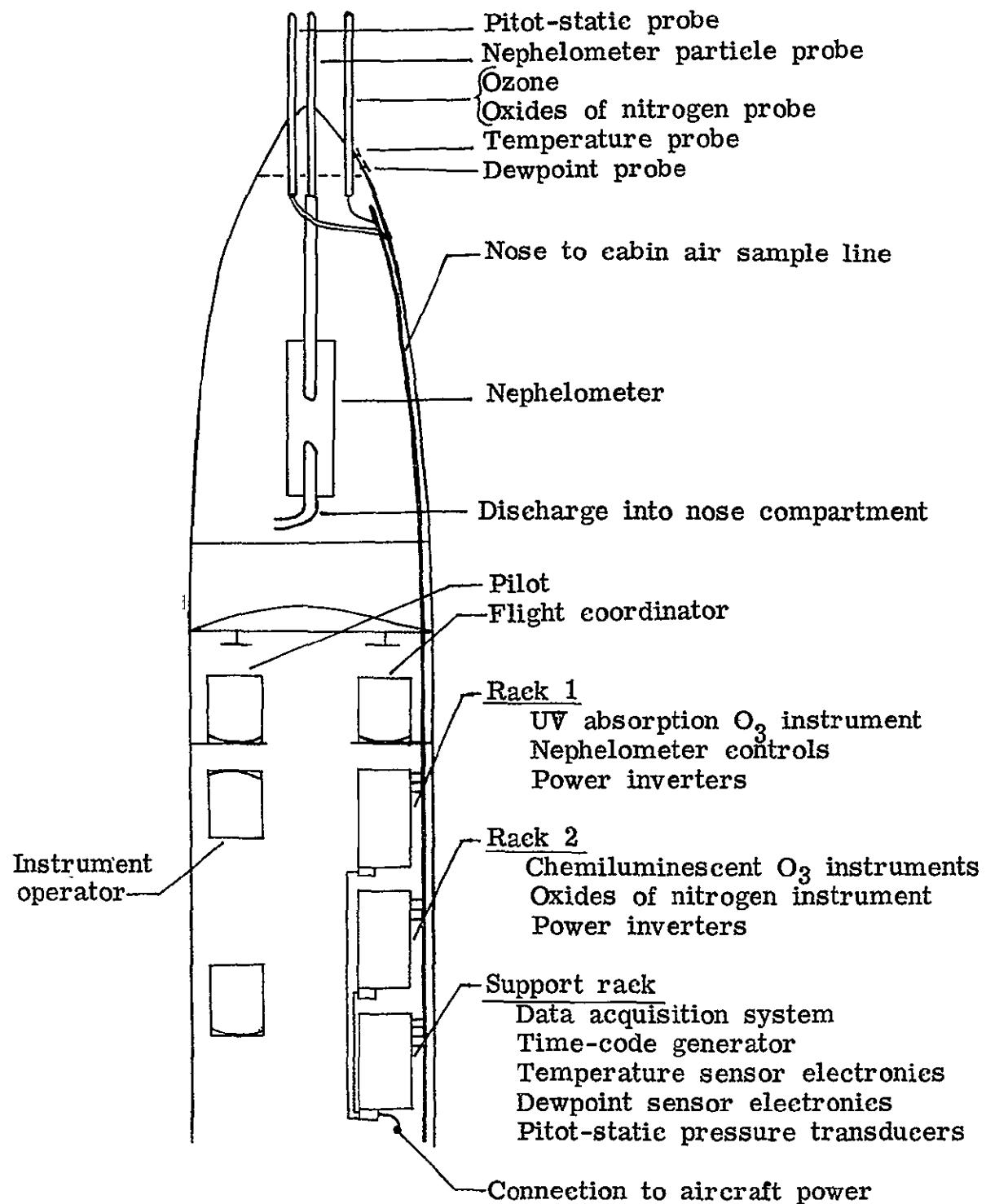


Figure 1 - Instrument configuration onboard NASA Cessna aircraft.

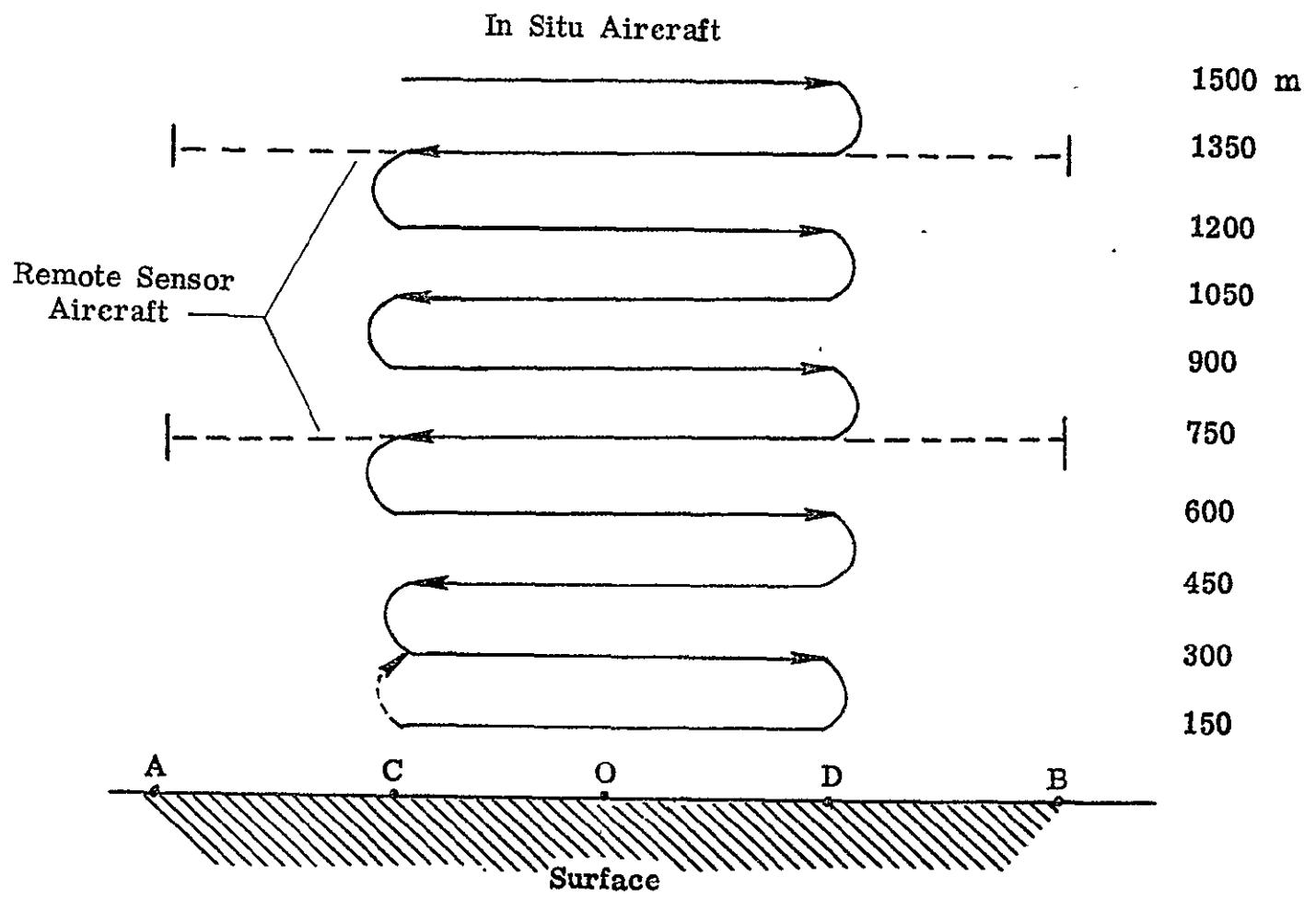


Figure 2 - Correlative Spiral experiment flight plan.

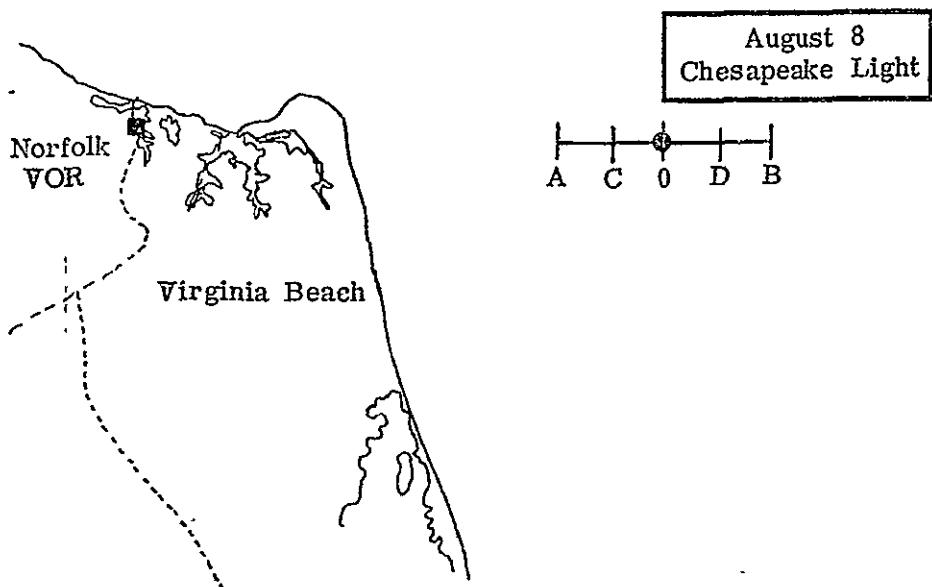
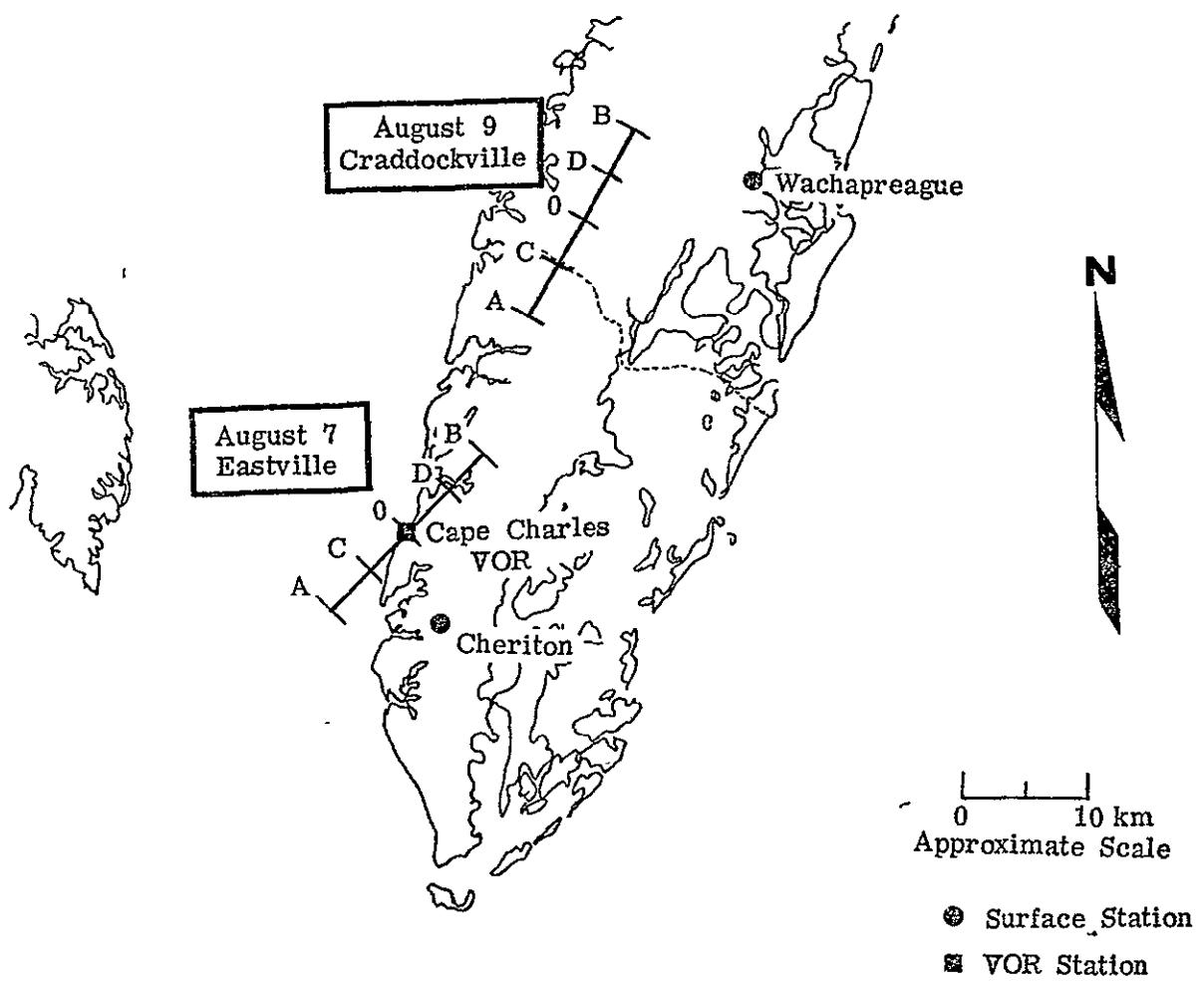


Figure 3 - Locations for Correlative Spiral experiments.

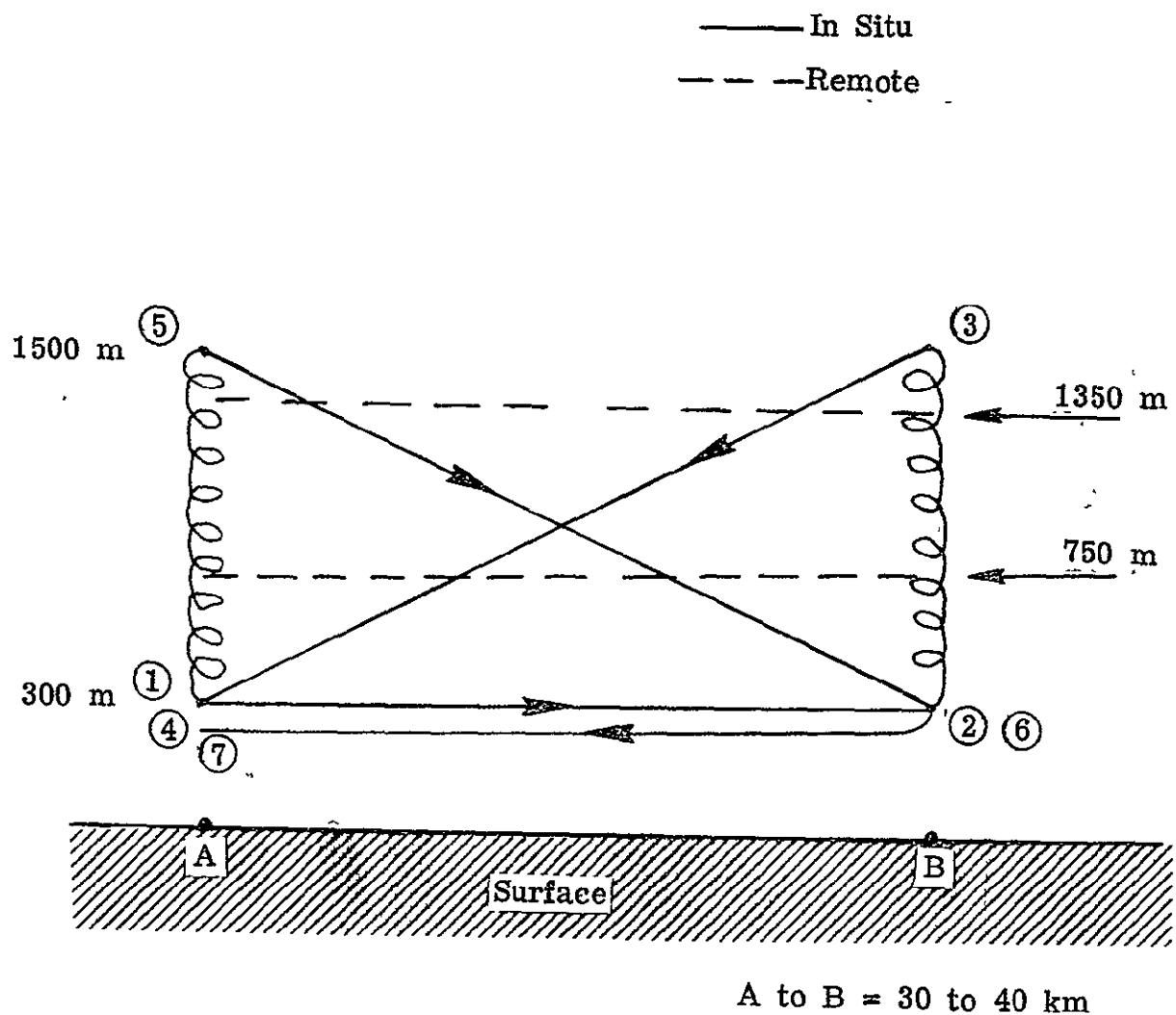


Figure 4 - Correlative Box Face experiment flight plan.

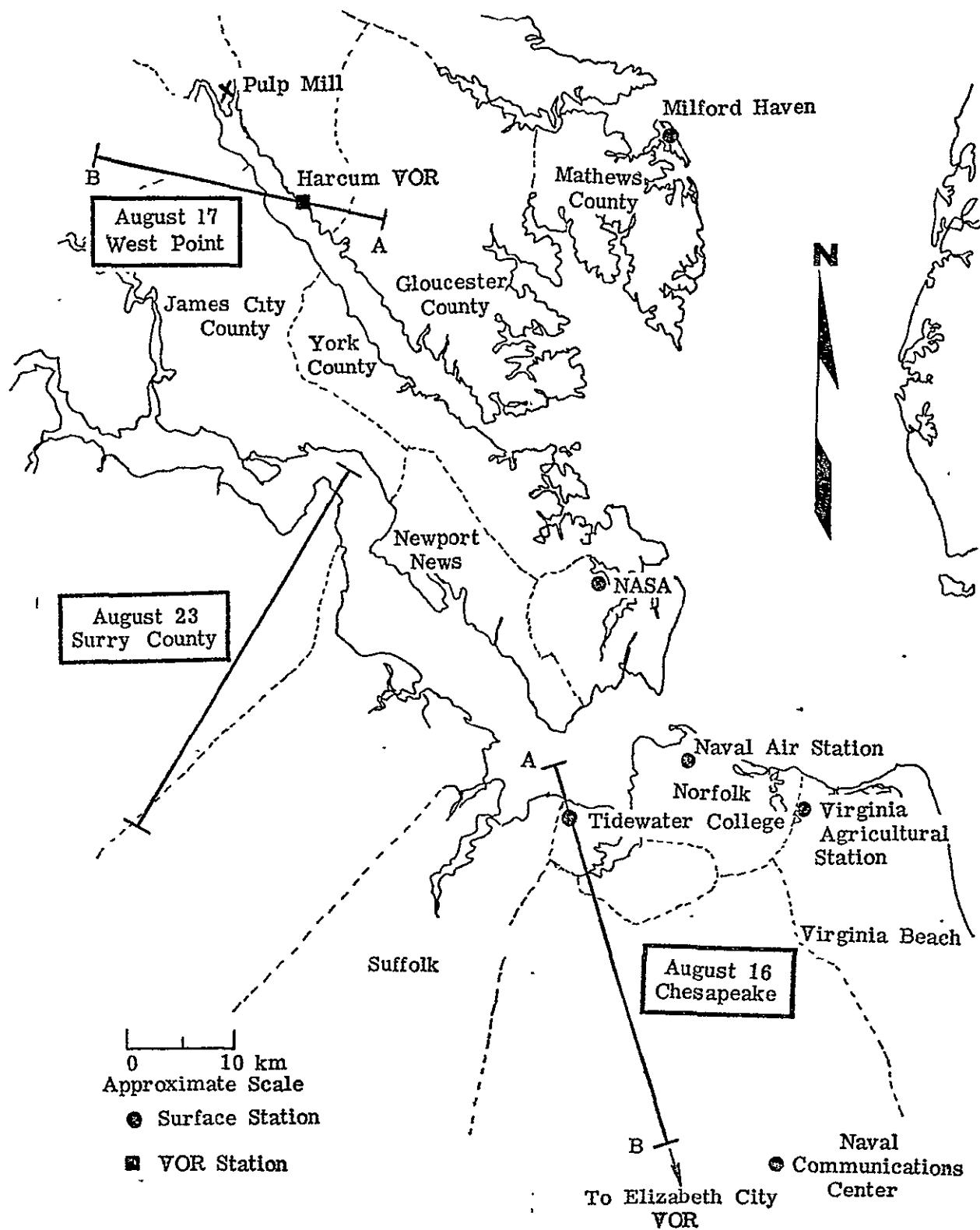


Figure 5 - Locations for Correlative Box Face experiments.

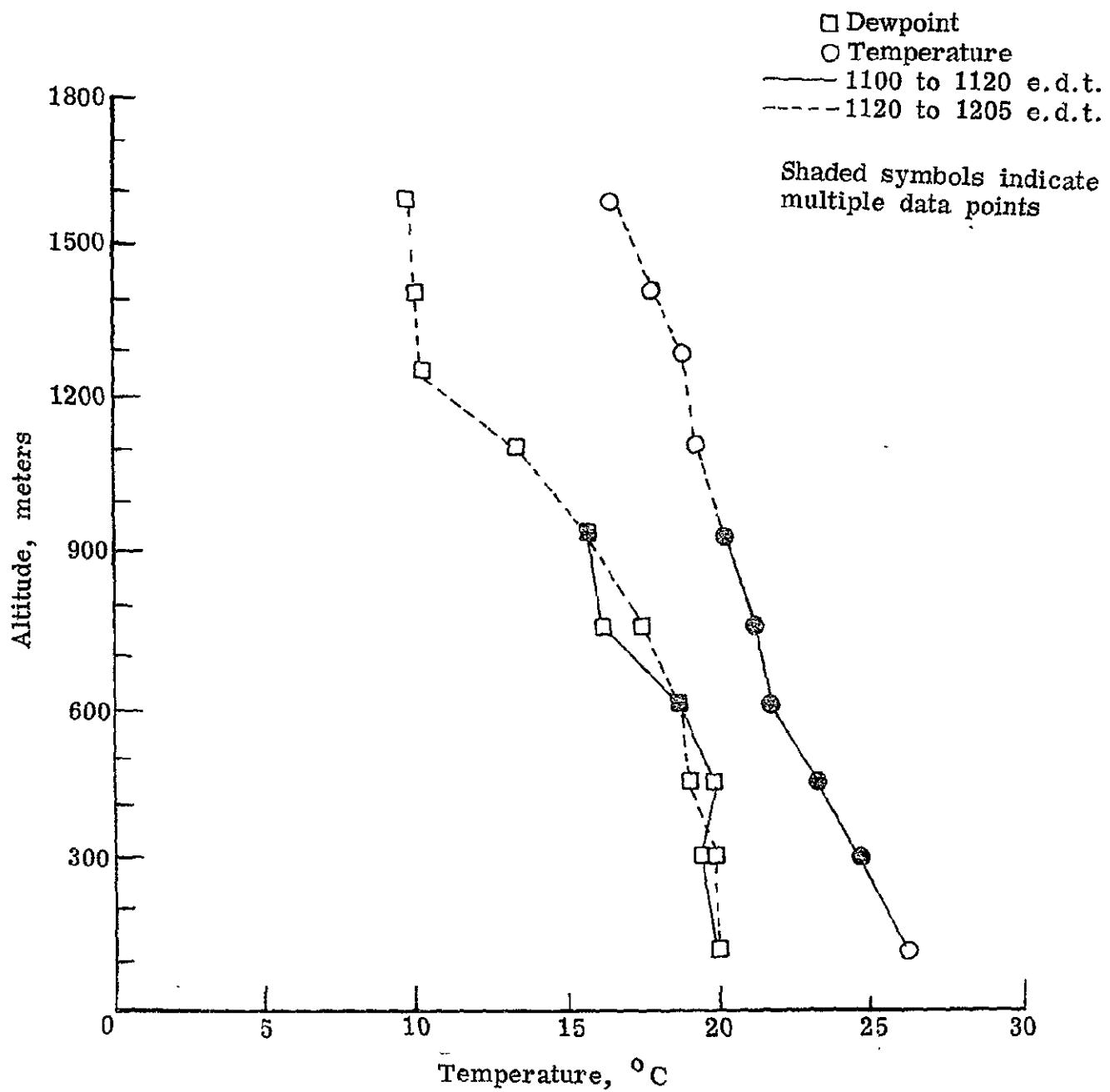


Figure 6 - Temperature and dewpoint profiles at Eastville; morning flight of August 7, 1979.

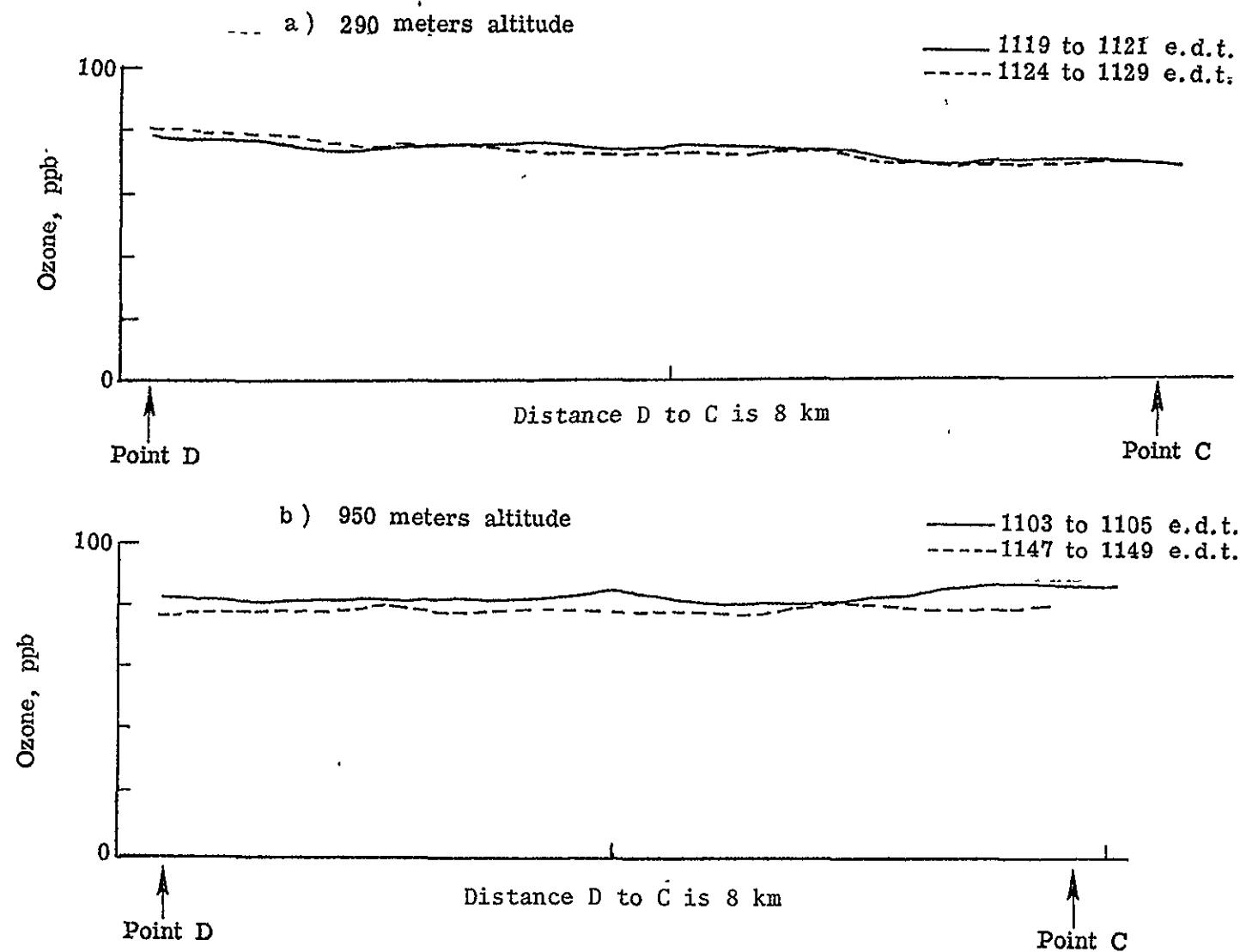


Figure 7 - Comparison of typical results for constant altitude flight legs at Eastville; August 7, 1979.

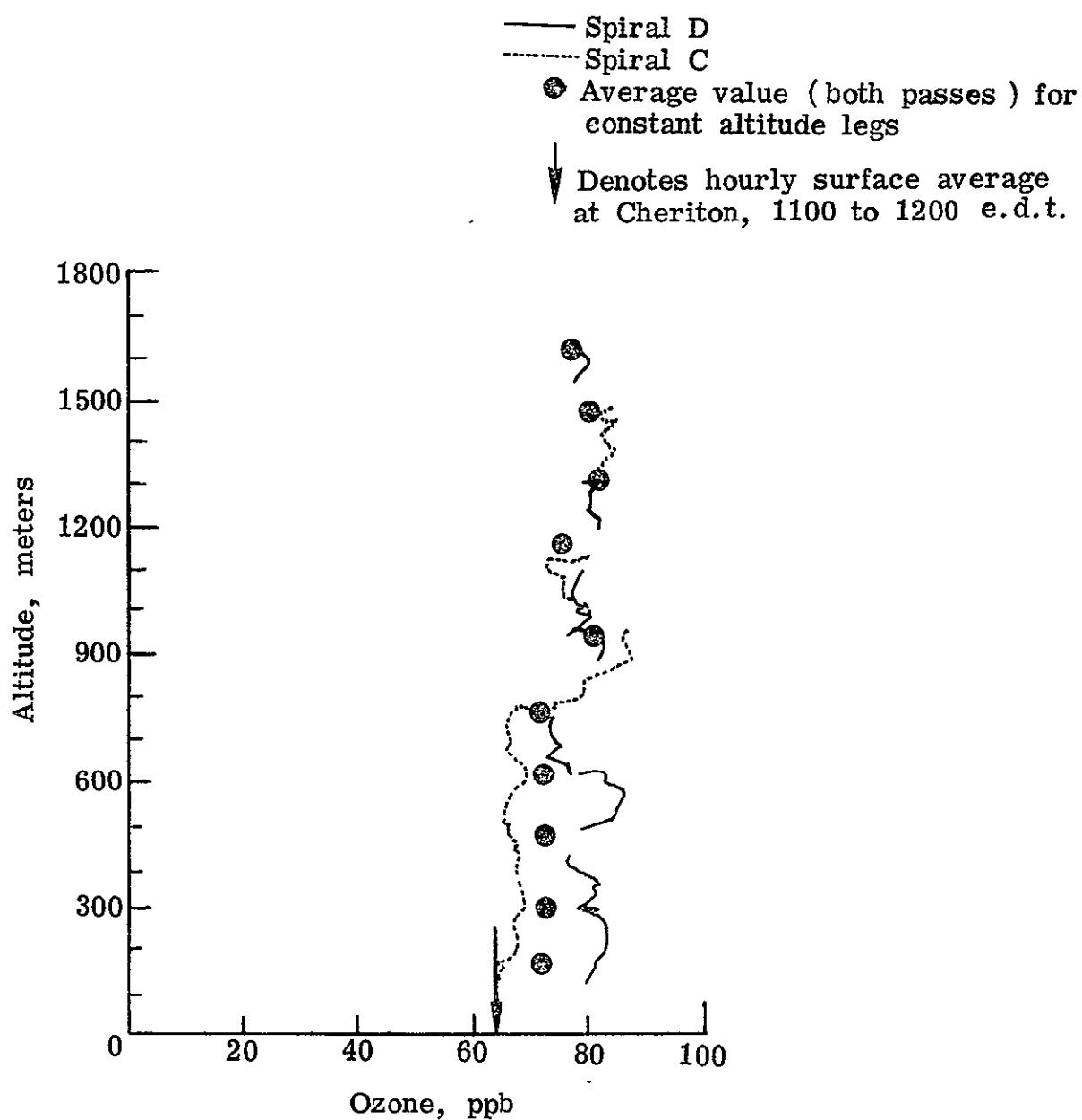


Figure 8 - Ozone profile for remote sensor comparison at Eastville; morning of August 7, 1979.

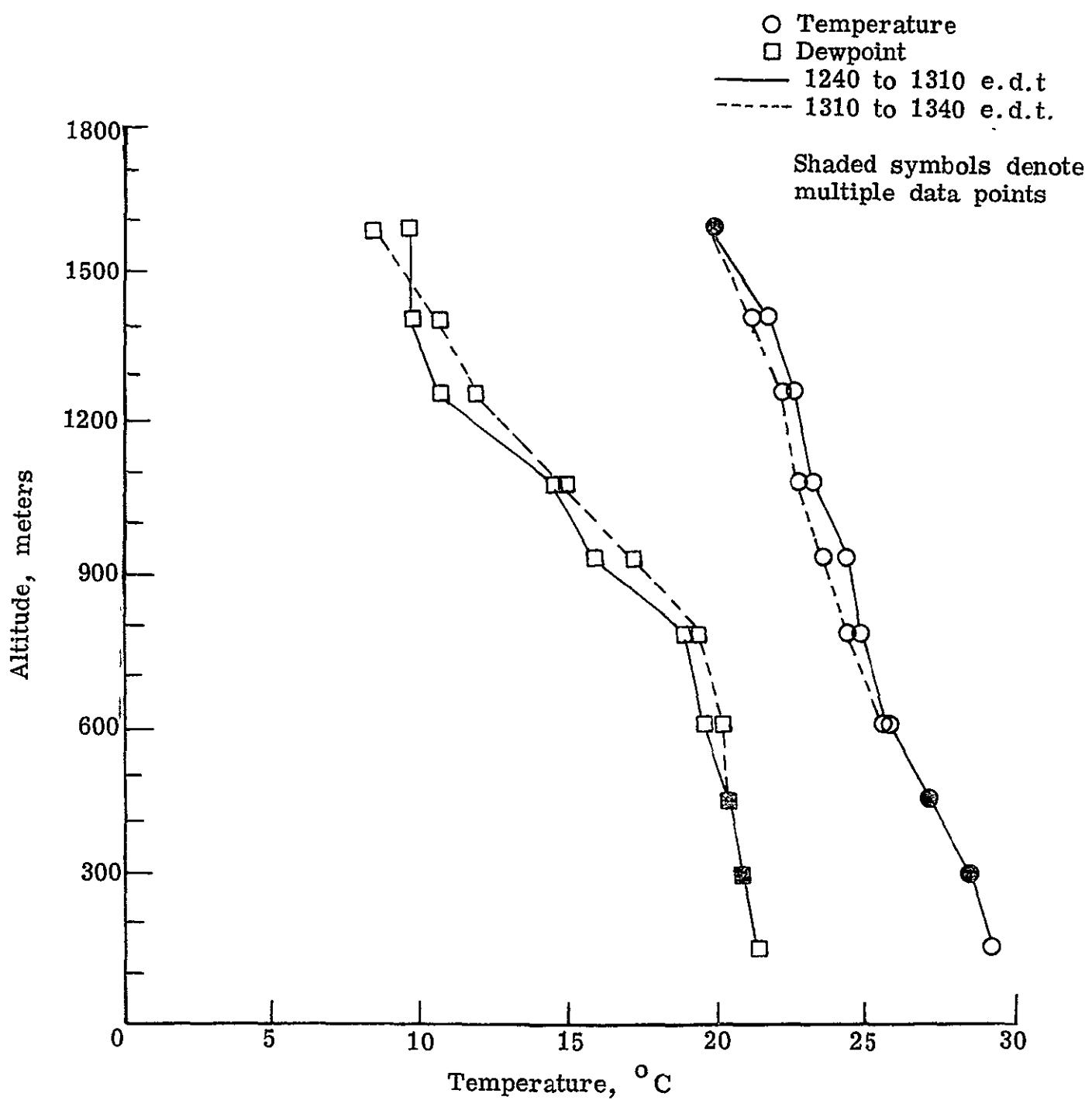


Figure 9 - Temperature and dewpoint profiles at Chesapeake Light; August 8, 1979.

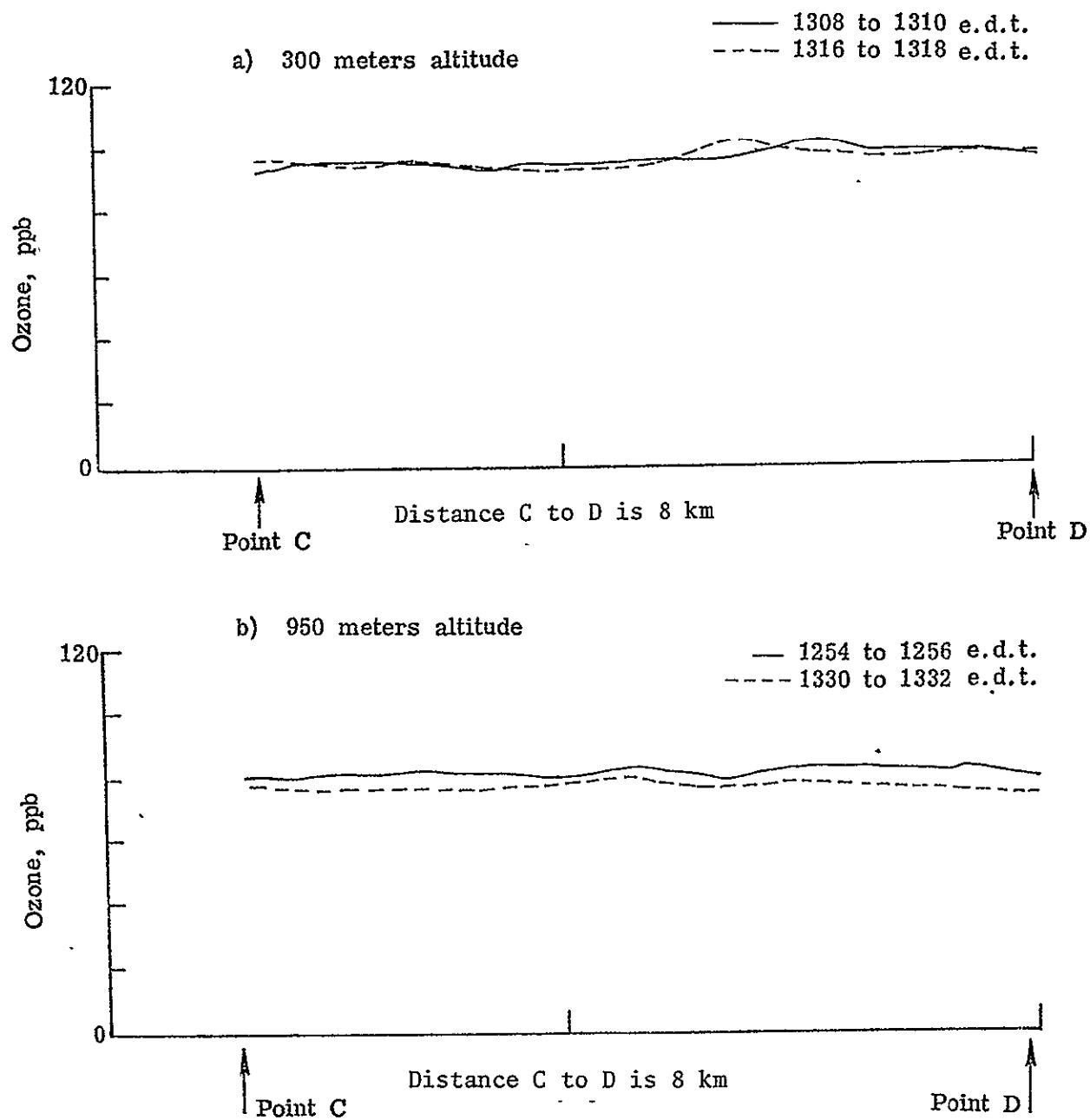


Figure 10 - Comparison of typical results for constant altitude flight legs at Chesapeake Light; August 8, 1979.

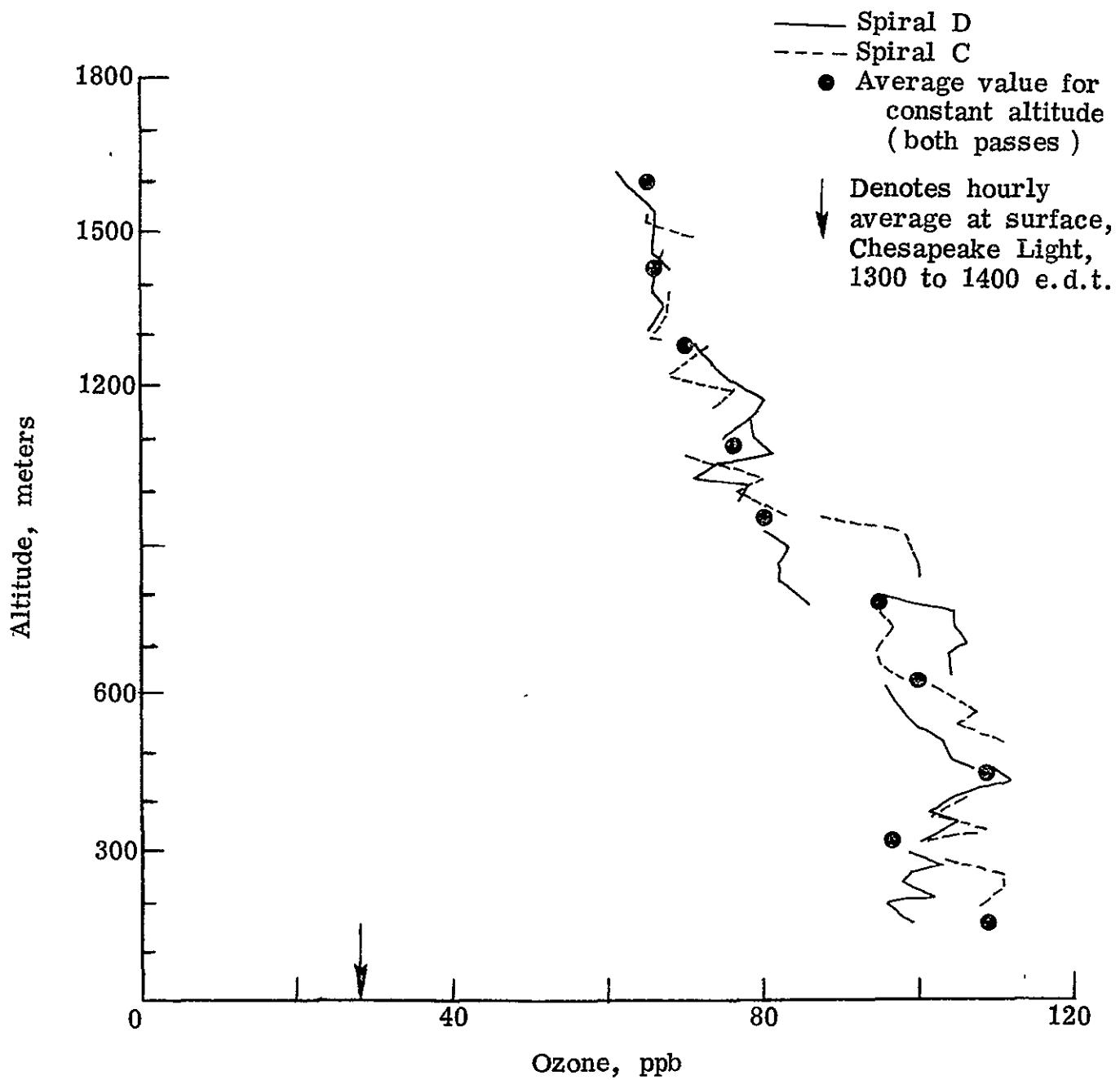


Figure 11 -- Ozone profile for remote sensor comparison at Chesapeake Light; August 8, 1979.

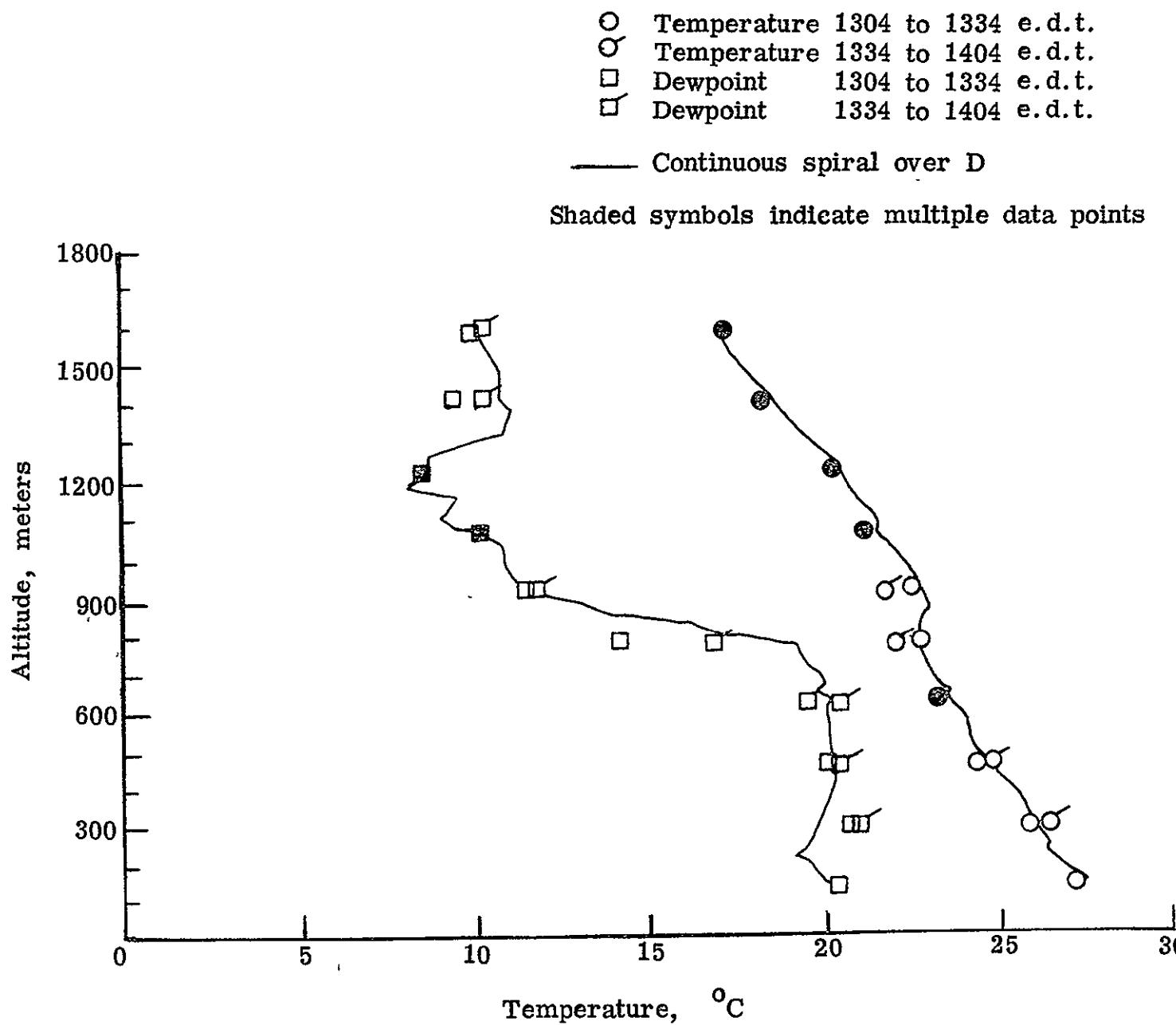
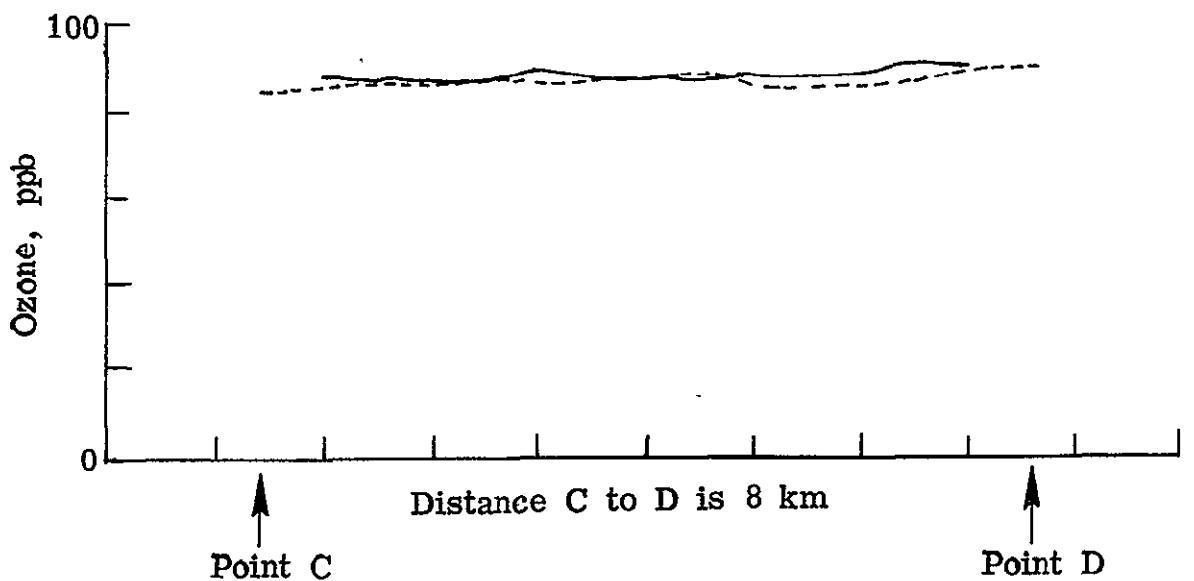


Figure 12 - Temperature and dewpoint profiles at Craddockville; August 9, 1979.

— 1329 to 1331 e.d.t.  
- - - 1337 to 1339 e.d.t.

a) 260 meters altitude



b) 910 meters altitude

— 1317 to 1319 e.d.t.  
- - - 1348 to 1350 e.d.t.

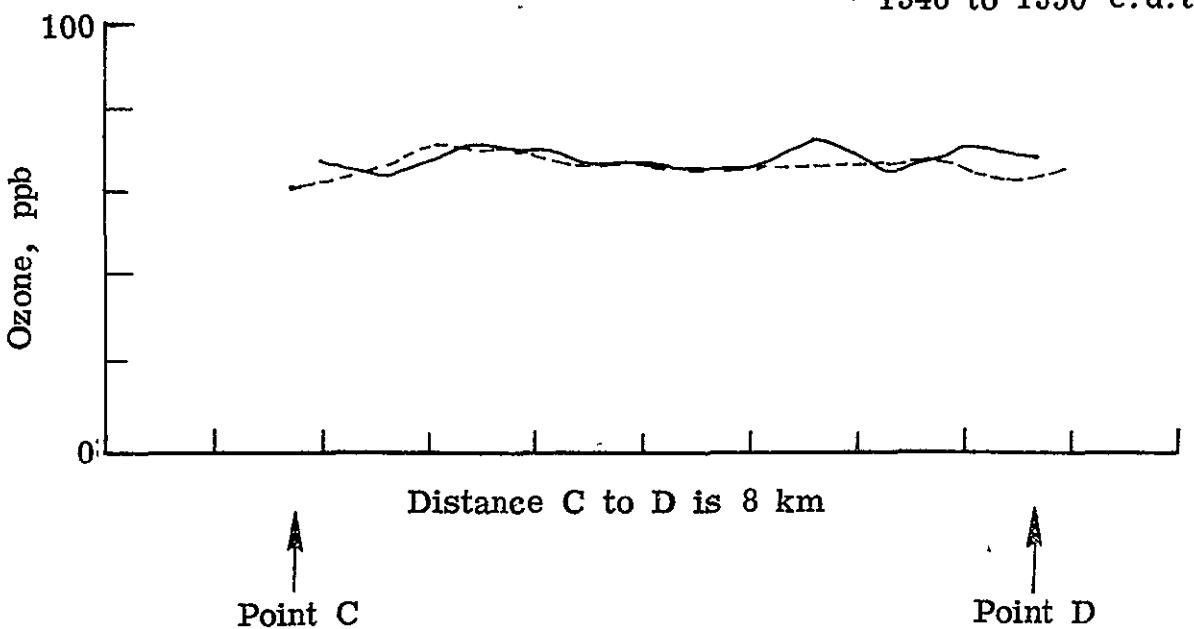


Figure 13 - Comparison of typical results for constant altitude flight legs at Craddockville; August 9, 1979.

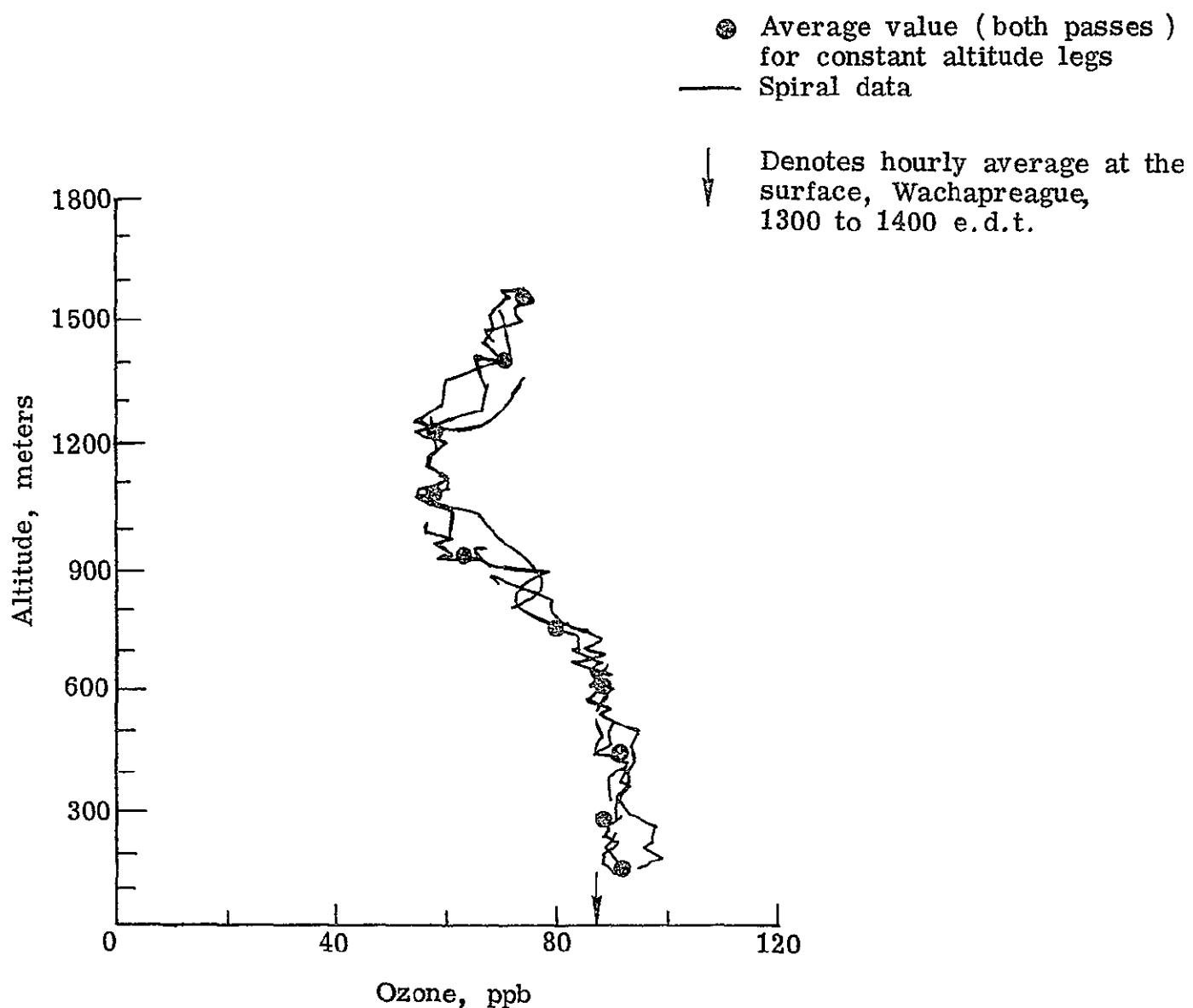


Figure 14 - Ozone profile for remote sensor comparison at Craddockville; August 9, 1979.

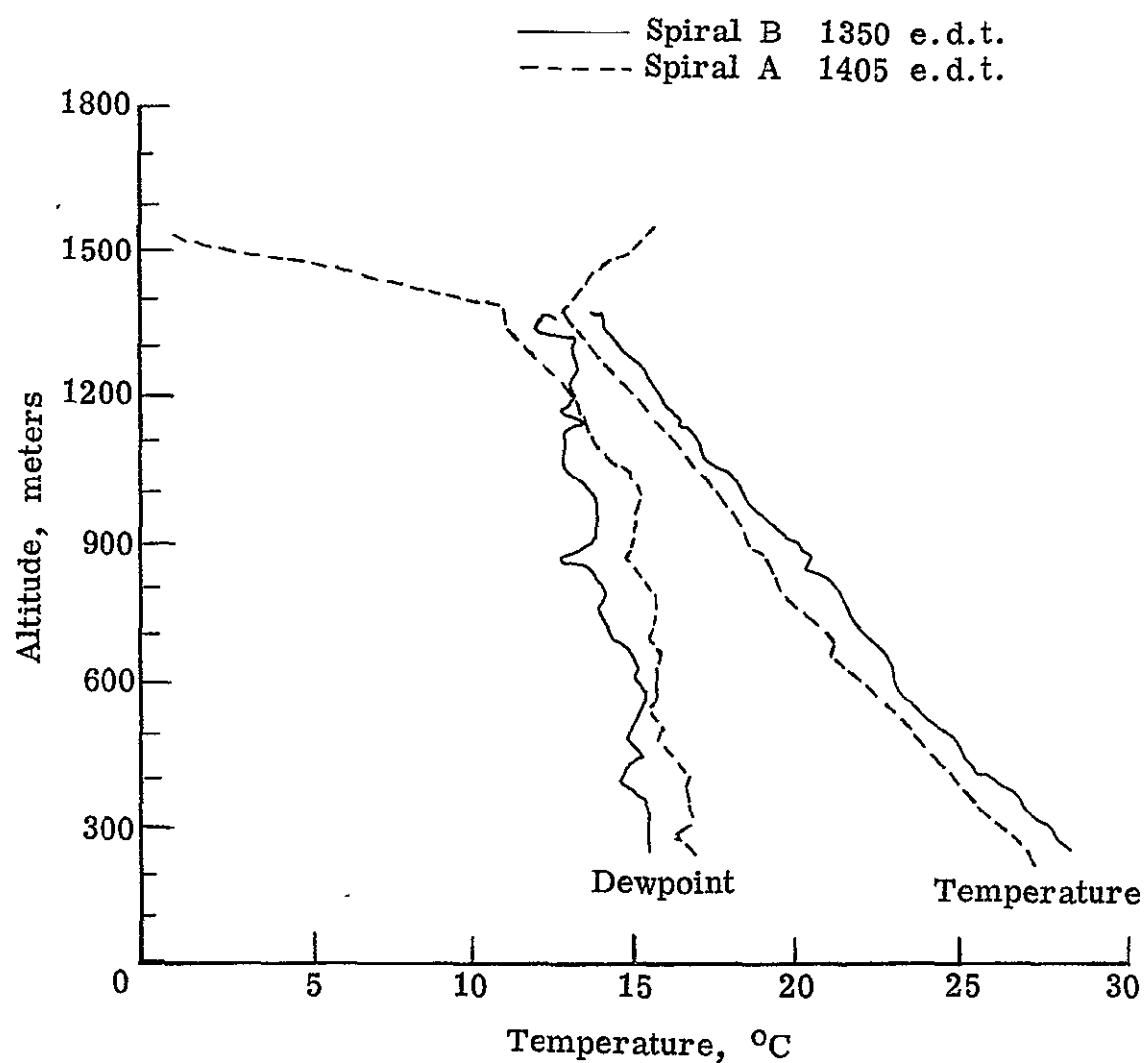


Figure 15 - Temperature and dewpoint profiles at Chesapeake; August 16, 1979.

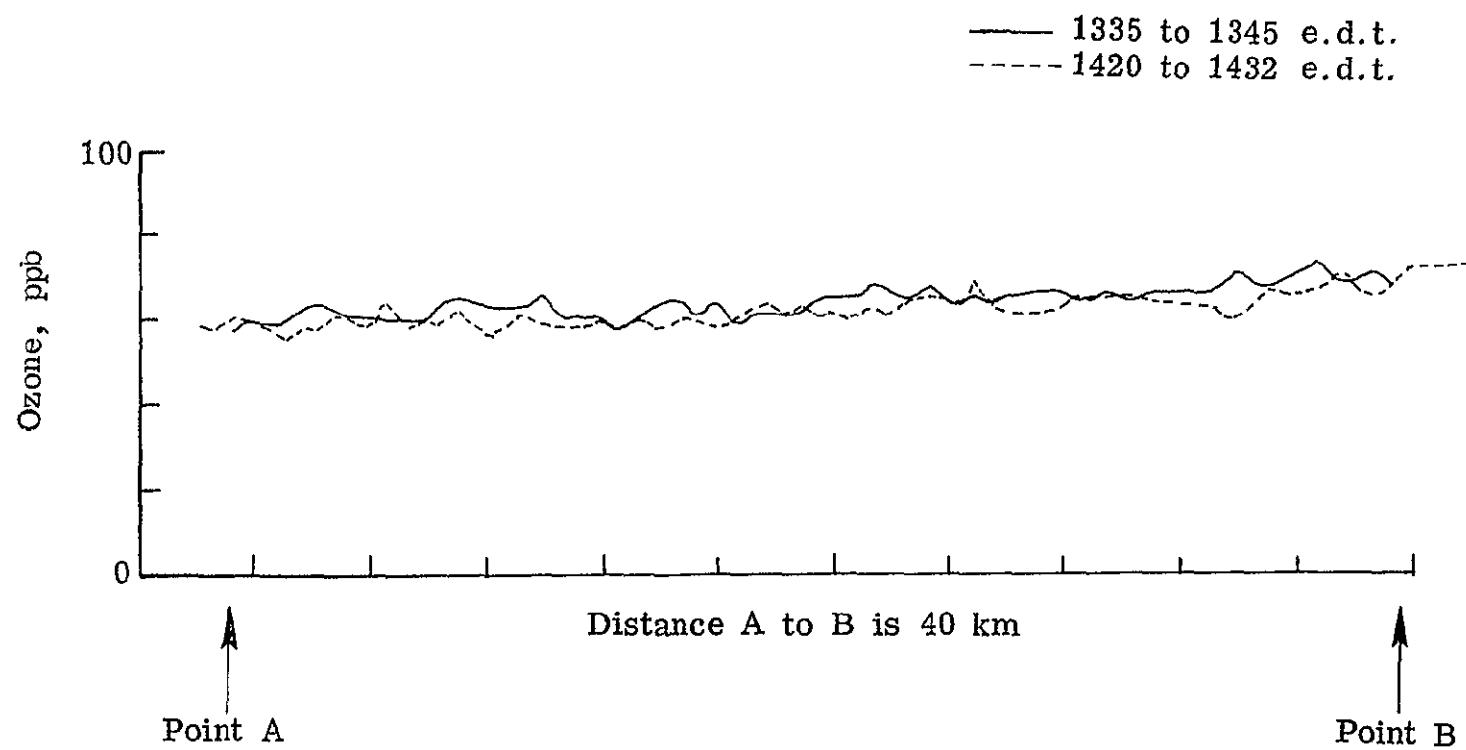


Figure 16 - Ozone constant altitude (220 meter) data at Chesapeake; August 16, 1979.

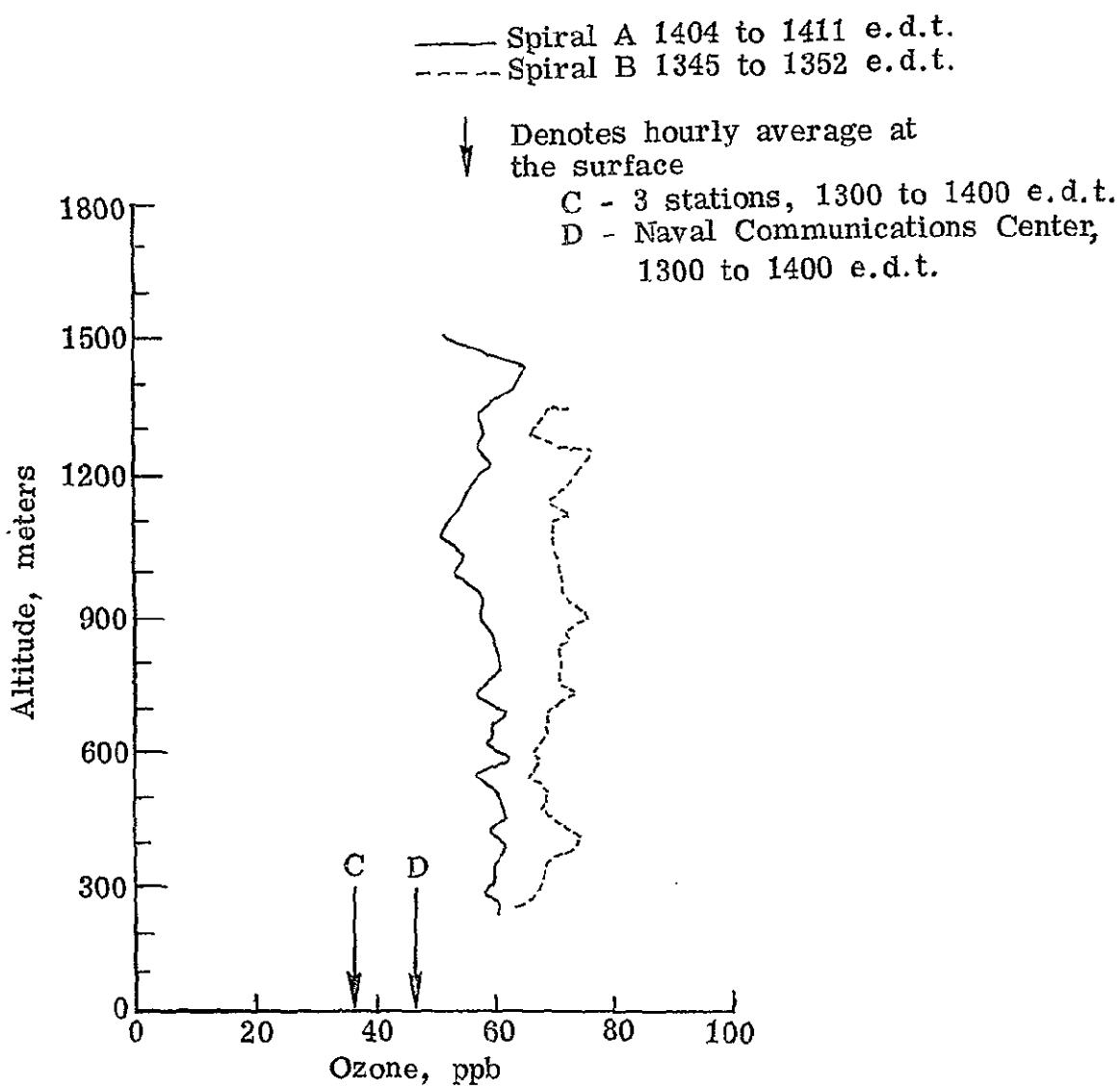


Figure 17 - Ozone spiral data at Chesapeake; August 16, 1979.

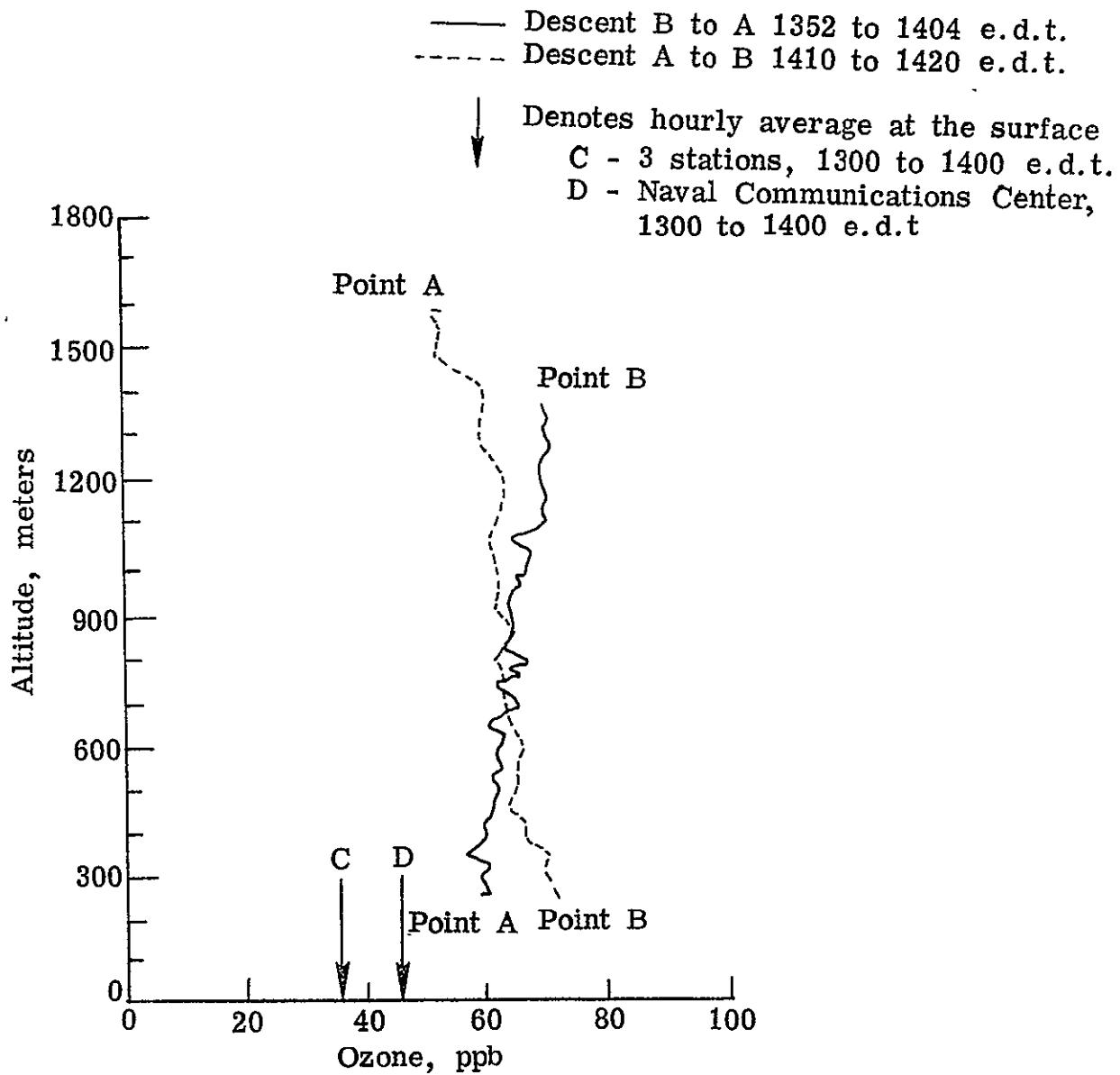


Figure 18 - Ozone profiles from constant descent (diagonal) flight legs at Chesapeake; August 16, 1979.

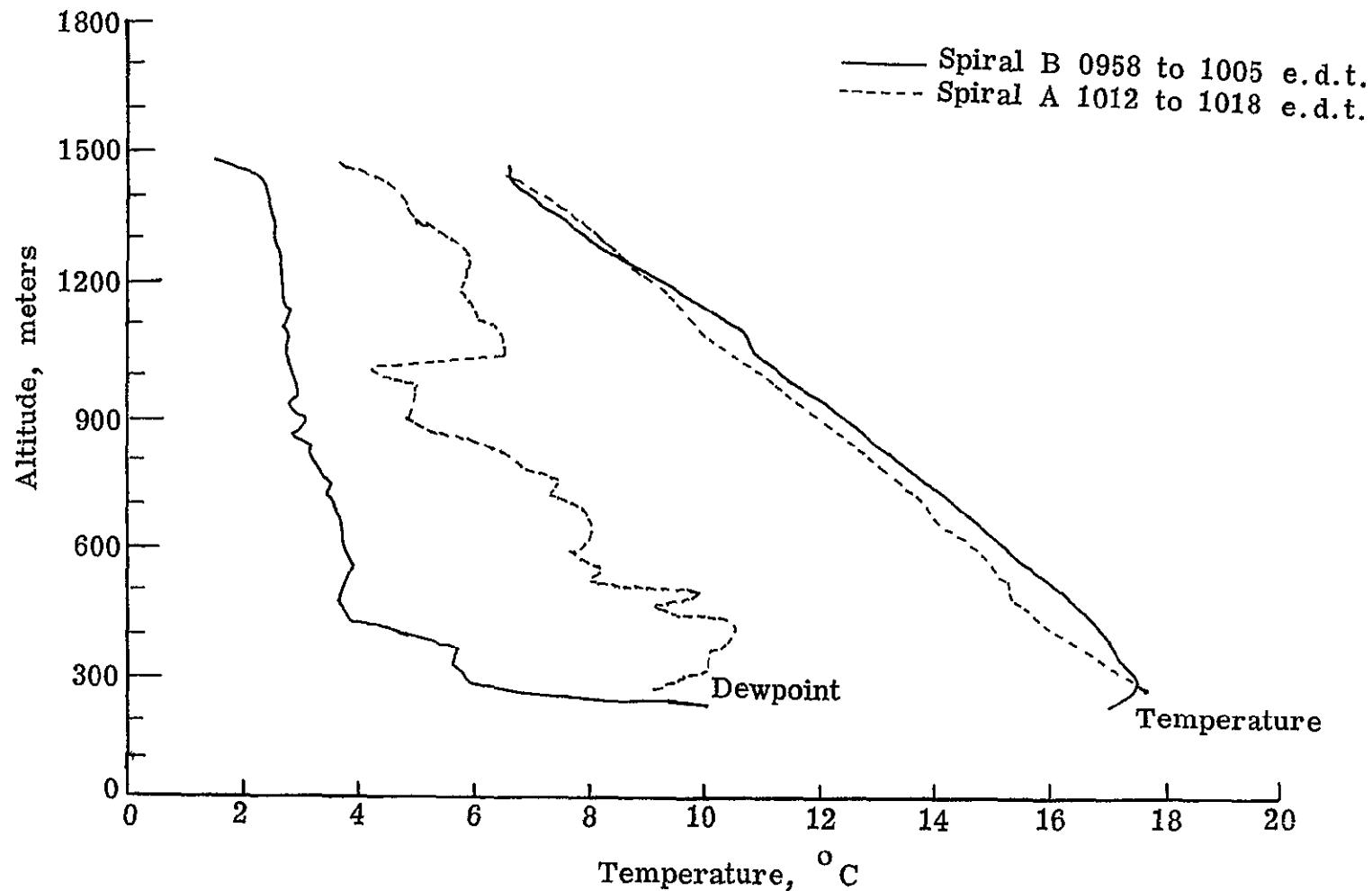


Figure 19 - Temperature and dewpoint profiles (spiral data) at West Point; August 17, 1979.

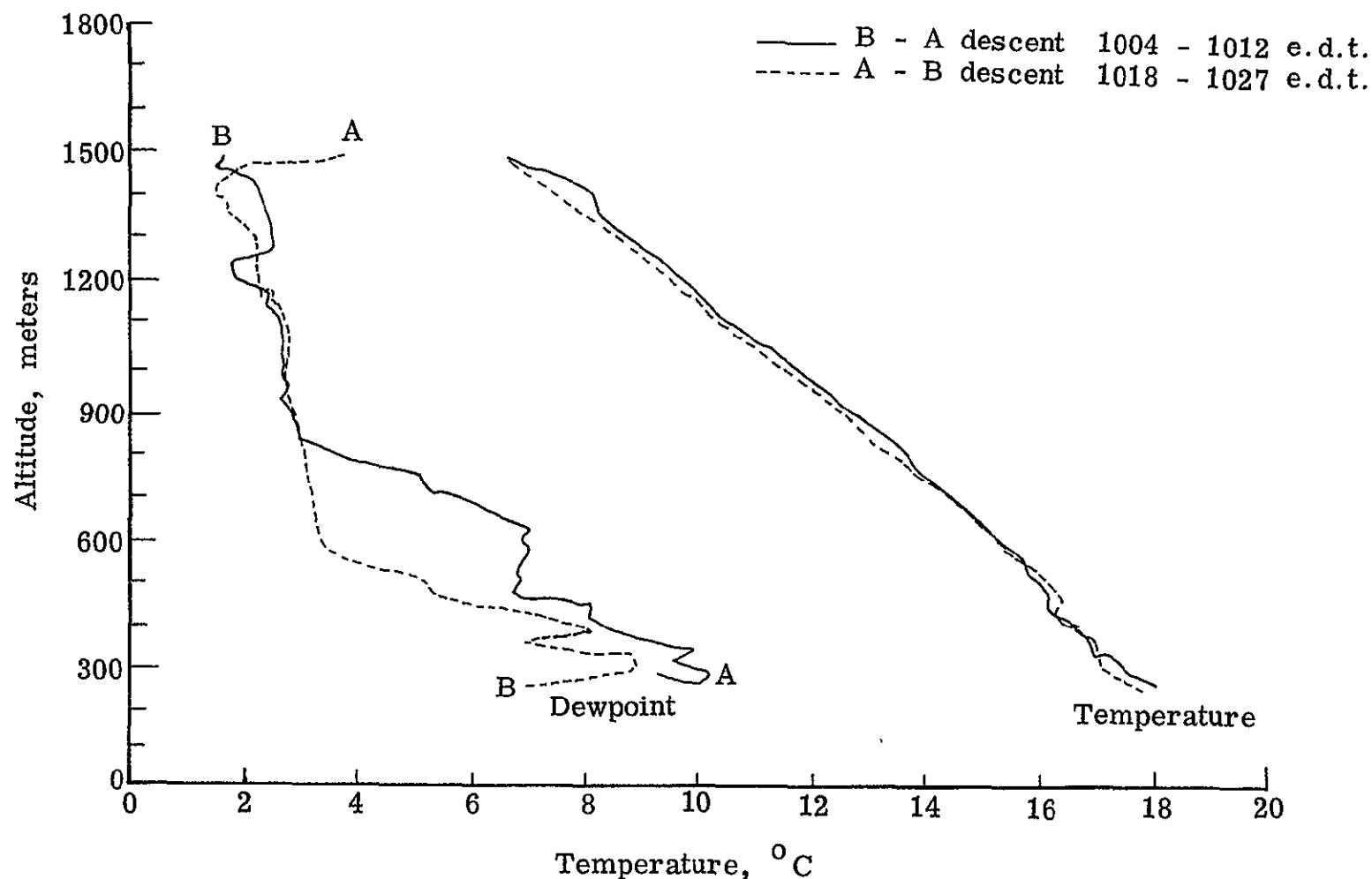


Figure 20 - Temperature and dewpoint profiles from constant descent (diagonal) flight legs at West Point; August 17, 1979.

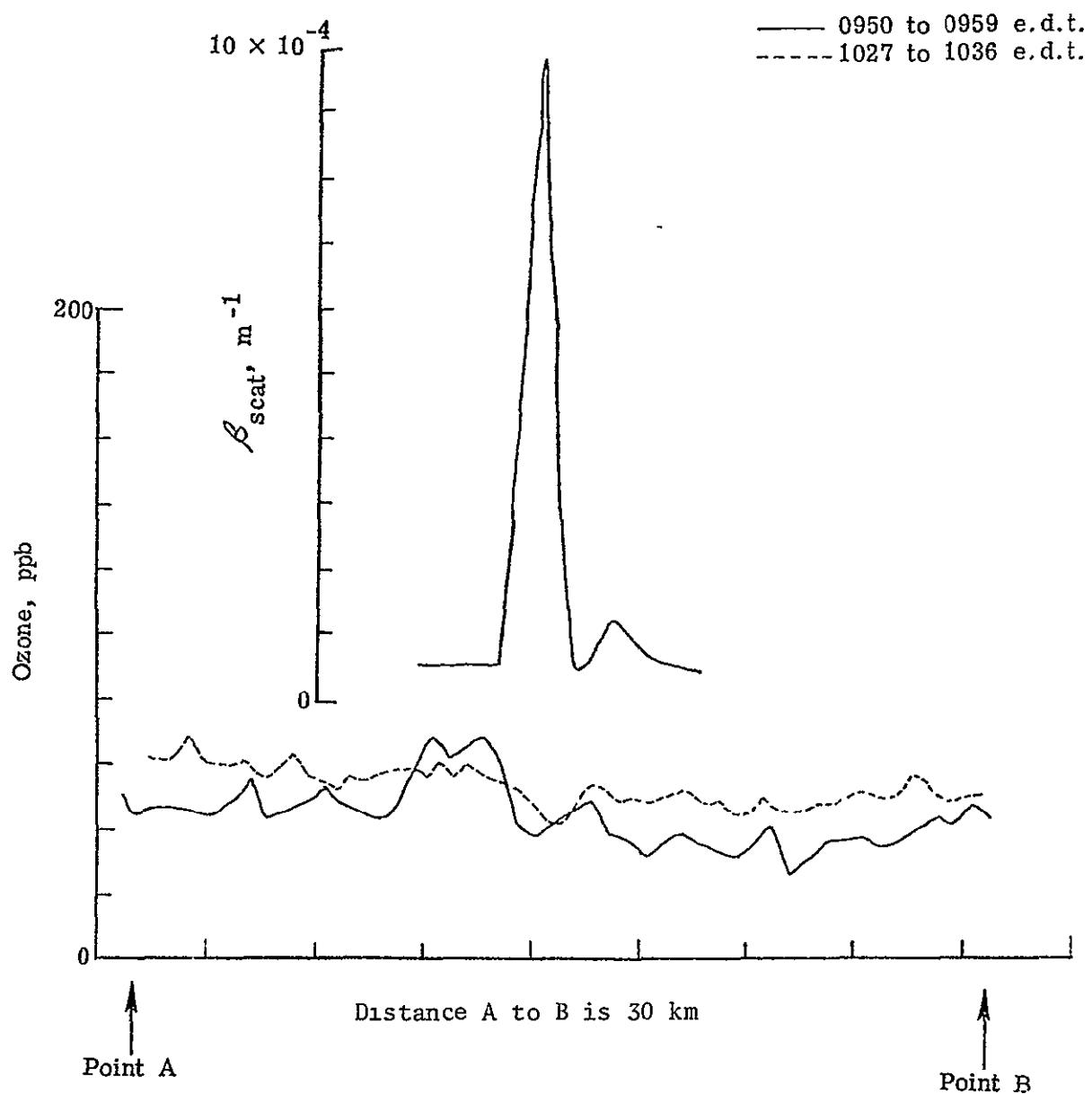


Figure 21 - Constant altitude (220 meter) data at West Point;  
August 17, 1979.

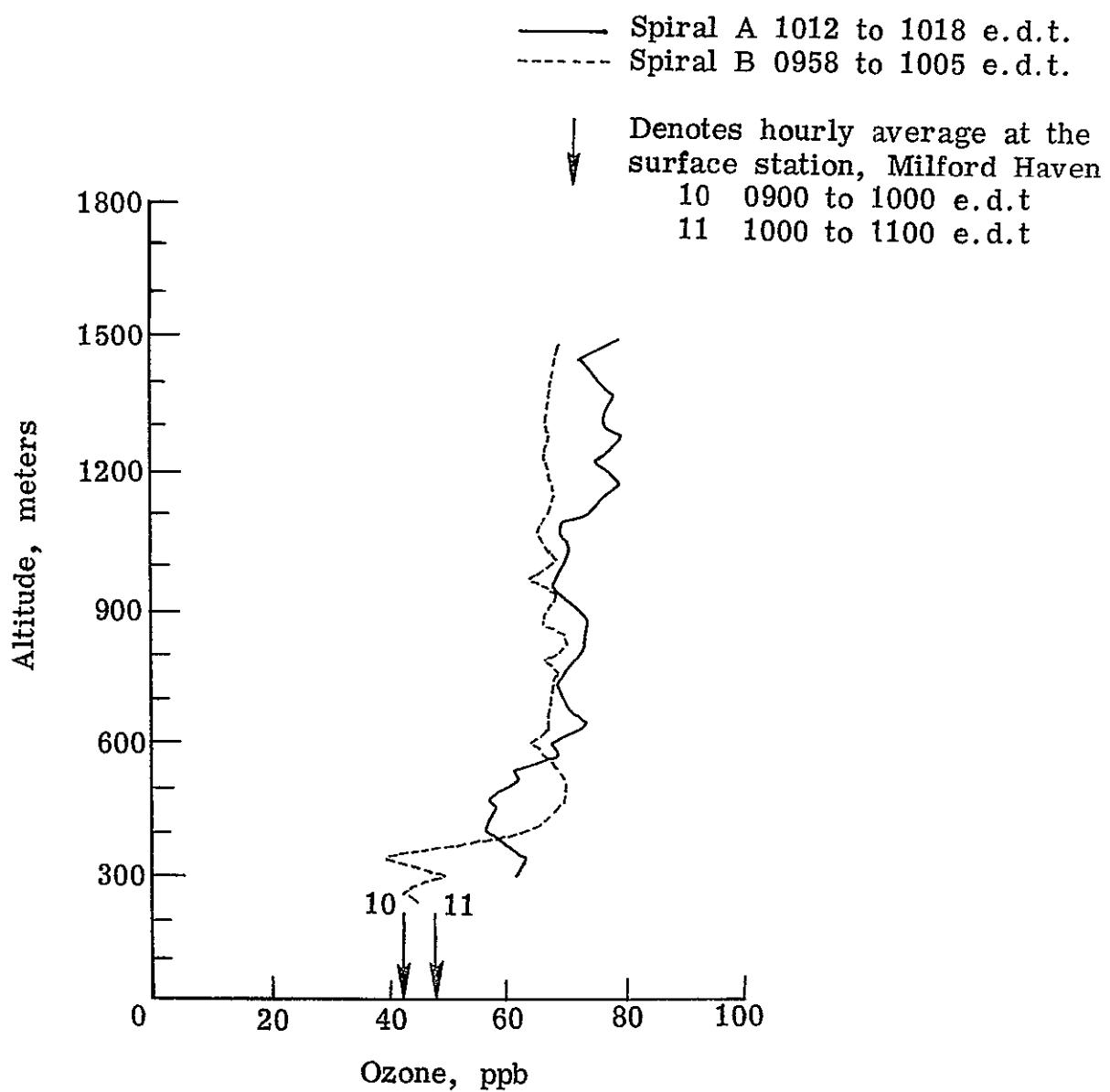


Figure 22 - Ozone spiral data at West Point; August 17, 1979.

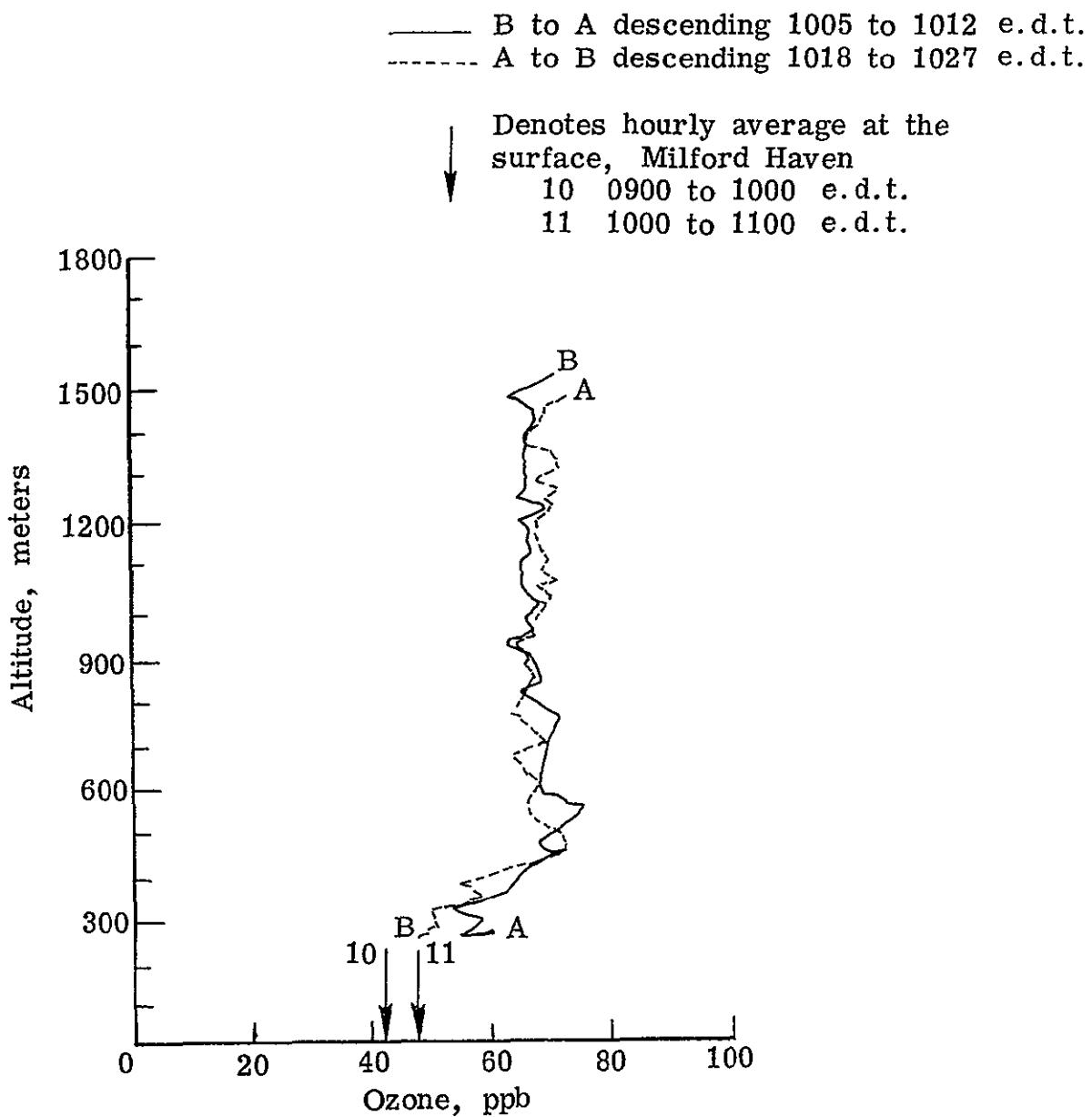


Figure 23 - Ozone profiles from constant descent (diagonal) flight legs at West Point; August 17, 1979.

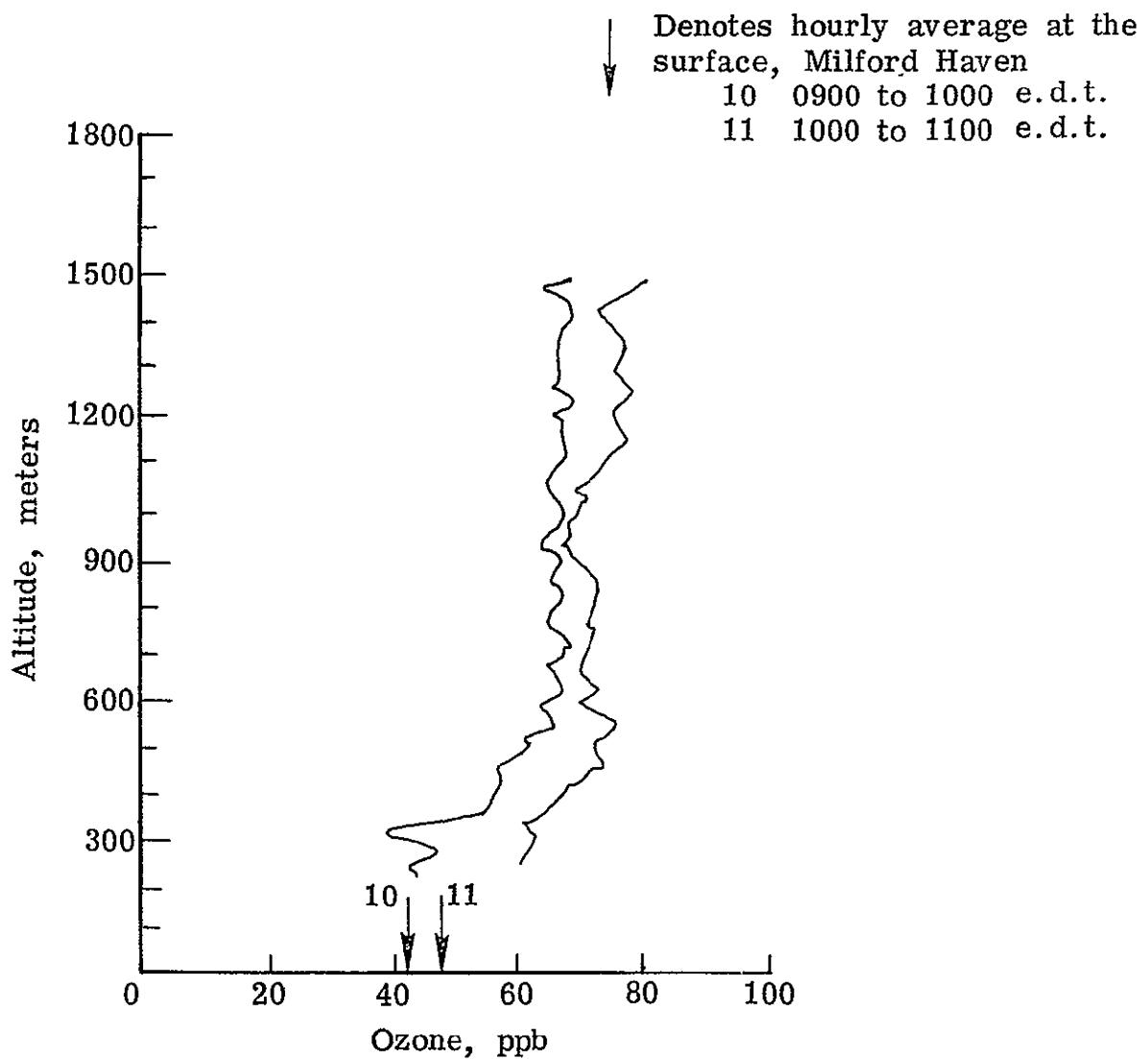


Figure 24 - Envelope of ozone data at West Point; August 17, 1979.

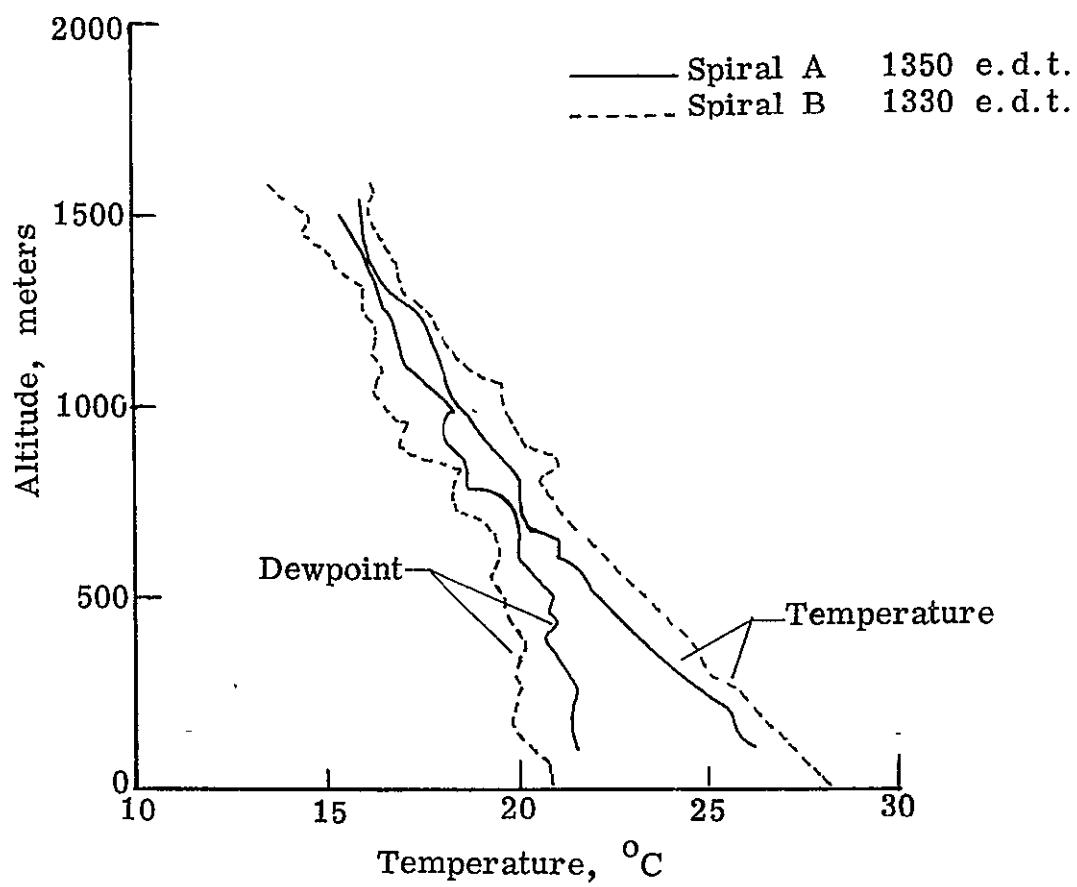


Figure 25 - Temperature and dewpoint profiles at Surry; August 23, 1979.

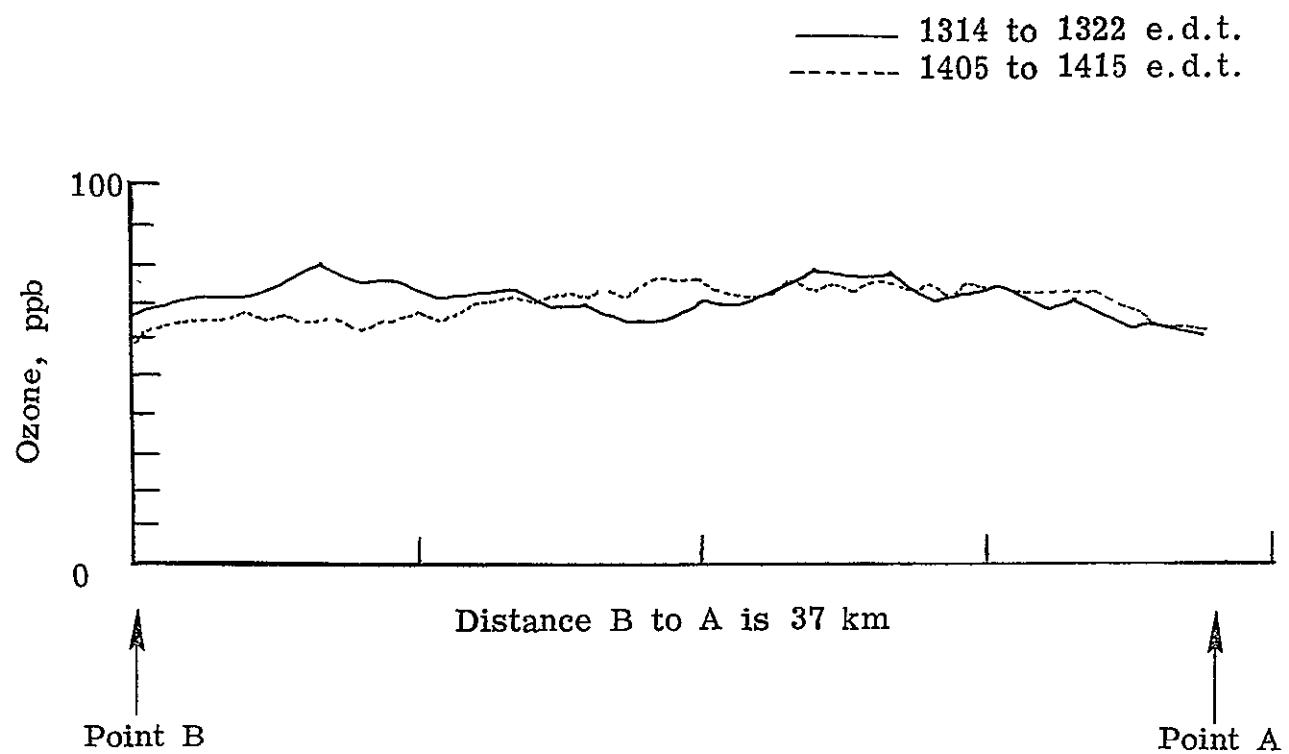


Figure 26 - Constant altitude (300 meter) ozone data at Surry;  
August 23, 1979.

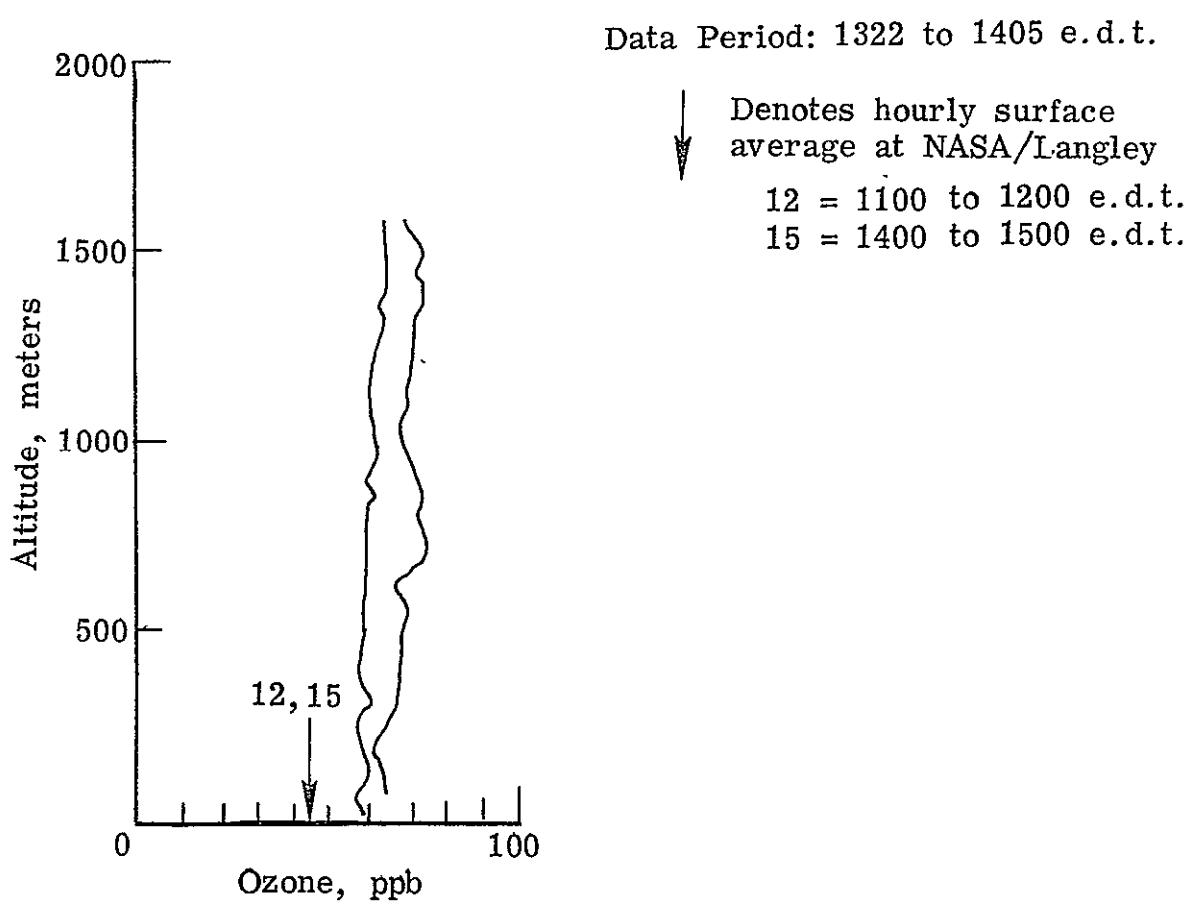


Figure 27 - Envelope of ozone data at Surry; August 23, 1979.

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| 15 Supplementary Notes  |  |  |                                |
| 16 Abstract<br><br>Ozone data from the 1979 Southeastern Virginia Urban Study (SEV-UPS) field program are presented. SEV-UPS, a part of NASA's Tropospheric Remote Sensor Evaluation program, was conducted during the month of August for evaluation of an ozone remote sensor, the Laser Absorption Spectrometer. During the measurement program, remote-sensor evaluation was in two areas; (1) determination of the remote sensor's accuracy, repeatability, and operational characteristics, and (2) demonstration of the application of remotely sensed ozone data in air-quality studies. Data from six experiments designed to provide in situ ozone data for evaluation of the sensor in area 1, above, are presented. Experiments consisted of overflights of a test area with the remote sensor aircraft while in situ measurements with a second aircraft and selected surface stations provided correlative ozone data within the viewing area of the remote sensor. The report presents only the in situ ozone data. From these data, calculated ozone burdens for comparison with the remote sensor are discussed. In addition, the report describes the ozone instrumentation, associated quality assurance program, and problems encountered with the use of the O <sub>3</sub> instrumentation. |  |  |                                |
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